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Upper Mystic Lake Watershed Urban Runoff Project: Main Report

Massachusetts Dept. of Environmental Quality
Engineering, Boston

Prepared for

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Oct 82

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The major objectives of this project were to:

1. Identify the quality and quantity characteristics of urban runoff in the Upper Mystic Lake Watershed;
2. Assess the impact of urban runoff on the Aberjona River and Upper Mystic Lake; and
3. Recommend controls to acheive quality goals in the Upper Mystic Lake.

With these objectives identified, the study was designed as a more comprehensive assessment of water quality conditions and as such, considered the various other sources of pollution and their relative contributions to the overall problem.

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UPPER MYSTIC LAKE WATERSHED URBAN RUNOFF PROJECT

MAIN REPORT

OCTOBER 1982

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UPPER MYSTIC LAKE WATERSHED

URBAN RUNOFF PROJECT

MAIN REPORT

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Massachusetts Department of Environmental Quality Engineering
Office of Planning and Program Management

October 1982

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The project staff would like to take this opportunity to acknowledge the many individuals who helped us throughout the project from other Divisions of DEQE, the Metropolitan District Commission, the Mass. Division of Fisheries and Wildlife, the U.S. Environmental Protection Agency and local officials and advisory committee members.

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1.0 INTRODUCTION

What is Urban Runoff?

Urban runoff is the water which comes off lawns, rooftops, streets and other paved areas during and after a rainstorm or as snow melt. As the runoff (or stormwater) travels, it picks up contaminants, including nutrients, sediments, metals, litter and organic and bacterial wastes, along its path. The streets may seem cleaner after a rainstorm, but in fact, the pollutants have merely been transferred to local catch basins and receiving waters. Additionally, greater volumes of water run off urban areas since a larger portion of the land is covered by structures and paved surfaces.

Why Are We Concerned?

Water quality conditions throughout the Upper Mystic Lake Watershed are generally below the state standards assigned by the Department of Environmental Quality Engineering, and fall short of the quality desired by local residents, particularly for recreation.

The value of the water resources in the Watershed has been recognized at the local, regional, state and federal levels as reflected by funds spent over the past 10 years for the study and control of pollution sources and by local interest demonstrated in this study. While several studies have identified urban runoff as a major pollution problem, the specific nature of urban runoff in the Watershed and its impact on water quality conditions have never been documented. This information is essential if water quality goals are to be attained and potential recreational opportunities fully realized.

Upper Mystic Lake Watershed Urban Runoff Project

The Upper Mystic Lake Watershed Urban Runoff Project is one of 28 prototype studies conducted across the country as part of the U.S. Environmental Protection Agency's (EPA) Nationwide Urban Runoff Program (NURP). This program was developed in response to a request from Congress for information on the magnitude of the stormwater problem nationwide and the advisability of making stormwater control facilities eligible for funding under EPA's Construction Grants Program. When the Clean Water Act was amended in 1977, Congress removed this eligibility on the grounds that there was not adequate information showing either that stormwater created water quality problems, impaired beneficial uses, or that stormwater could be effectively controlled. Thus, EPA developed the NURP program whose objectives are to determine the nature, cause and severity of urban runoff problems, and opportunities for controlling these problems.

The availability of funds under the NURP program provided an excellent opportunity to gather the information required on urban runoff as a source of pollution in the Upper Mystic Lake Watershed. The Mystic Project competed favorably with other proposals because of the water quality work done in the past, and the local, regional and state commitment to improving water quality conditions.

The major objectives of the Mystic Project were:

- To identify the quality and quantity characteristics of urban runoff in the Upper Mystic Lake Watershed;
- To assess the impact of urban runoff on the Aberjona River and Upper Mystic Lake; and
- To recommend controls to achieve quality goals in the Upper Mystic Lake.

While these objectives were specific to urban runoff, the study was designed as a more comprehensive assessment of water quality conditions and as such, considered the various other sources of pollution and their relative contributions to the overall problem.

Project Reporting

The results of this project are important at the local, regional, state and federal levels, but the objectives of each with regard to pollution control vary to some degree. Local citizens and officials are interested in learning about the major sources of pollution in their community and the Watershed as well as what can be done to improve local water quality. State and regional agencies share these concerns but also want to consider the implications of the results for other areas and the transfer of modelling techniques. At the national level this project's results will be added to a growing data base used to report back to Congress on the magnitude of stormwater problems nationwide.

These varying objectives require different levels of detail in terms of the information presented, making it difficult to write one report which will effectively meet everyone's needs. Consequently, two reports have been written: this, the MAIN REPORT, which provides the technical detail required by the NURP staff, state and regional agencies, and a SUMMARY REPORT designed more for local use. While the MAIN REPORT is fairly technical in nature, we have provided a glossary of terms to enable anyone who would like to delve deeper into the results to do so.

In addition to these two volumes, our consultants, Camp Dresser and McKee, Inc. (CDM), have prepared a number of reports dealing with various aspects of the project as listed here:

CDM, 1980a. *Upper Mystic Lake NURP Case Study - Precipitation Analysis*.

___, 1980b. *Aberjona River Basin Water Quality Summary*.

___, 1981b. *Coliform Correlation Analysis Using Existing Data*.

___, 1982. *Upper Mystic Lake Nationwide Urban Runoff Program Case Study*.

The findings of CDM's reports serve as the basis for a portion of the analysis presented in this report.

2.0 STUDY AREA

The purpose of this chapter is to provide a general description of the Upper Mystic Lake Watershed, its physical characteristics and growth and development patterns. This information provides a framework for our consideration of water quality conditions of the Upper Mystic Lake and throughout the Watershed. While most of the material presented in this chapter is taken from other published reports, several sections do contain new or revised information.

The Lake Morphology section presents revised Lake dimensions and water volumes based on our field studies. For our hydrology analysis, flow rates for the inlets, overland runoff and groundwater were estimated and a water budget for the Lake was computed. Water circulation patterns in the Lake are also considered based on our field studies. Additionally, the Growth and Development section includes the results of a survey conducted regarding water uses throughout the Watershed.

2.1 DESCRIPTION OF THE UPPER MYSTIC LAKE WATERSHED

The Upper Mystic Lake Watershed covers 28.0 square miles and comprises the northern portion of the Mystic River Basin which is located in eastern Massachusetts extending northeast from Boston Harbor. The Watershed covers portions of nine communities: Arlington, Burlington, Lexington, Medford, Reading, Stoneham, Wilmington, Winchester, and Woburn (see Figure 2-1). Two major interstate highways, Routes 93 and 95, cross the Watershed in its northern and eastern sections as shown in Figure 2-2.

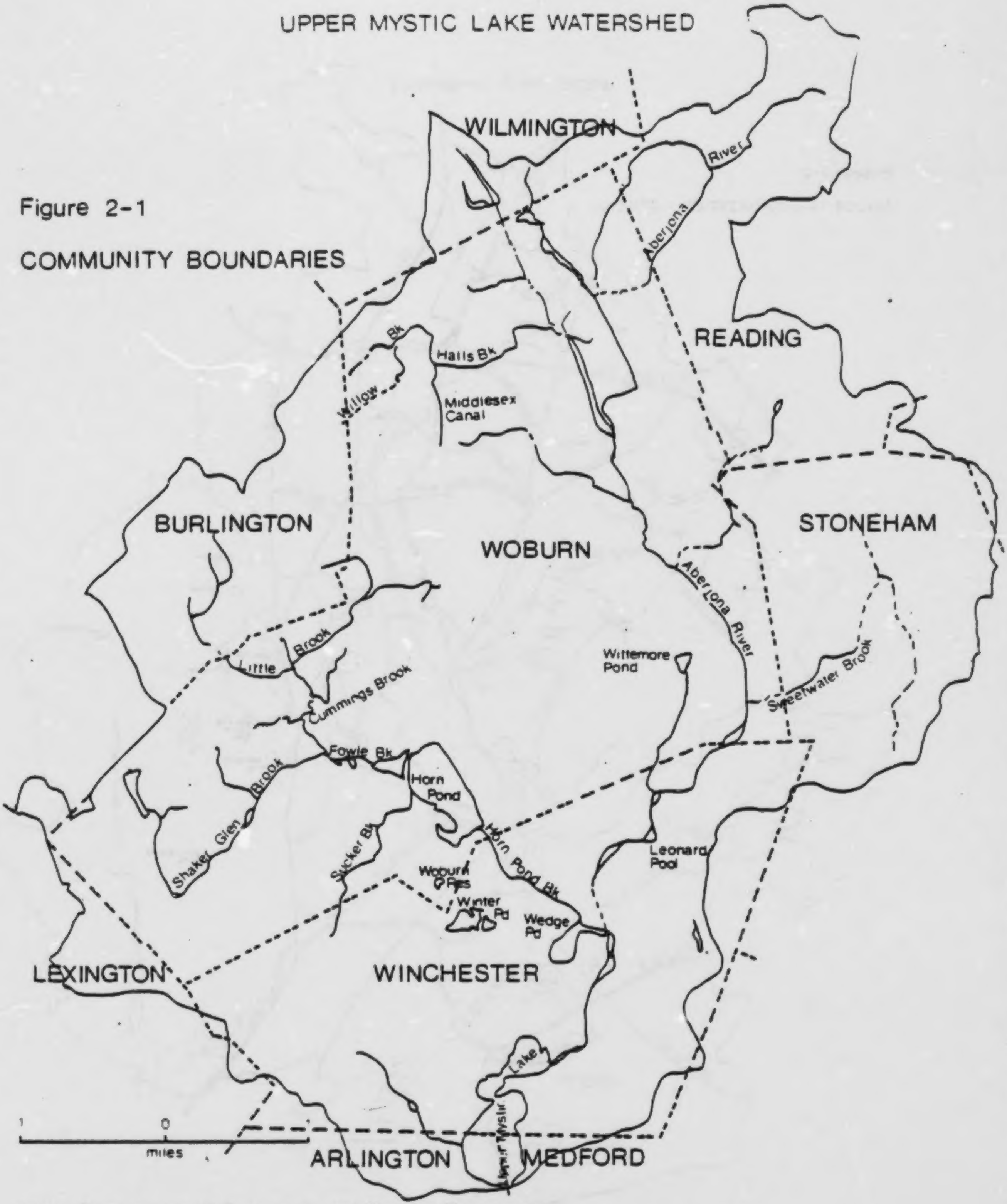
Geology

The Upper Mystic Lake Watershed, like most of eastern Massachusetts, is underlain by metamorphic and igneous rocks, primarily granite and gneiss, formed during the Precambrian and Paleozoic Ages, one billion to 300 million years ago. After formation this bedrock went through a long period of uplifting and dissection by stream erosion. This process was interrupted by

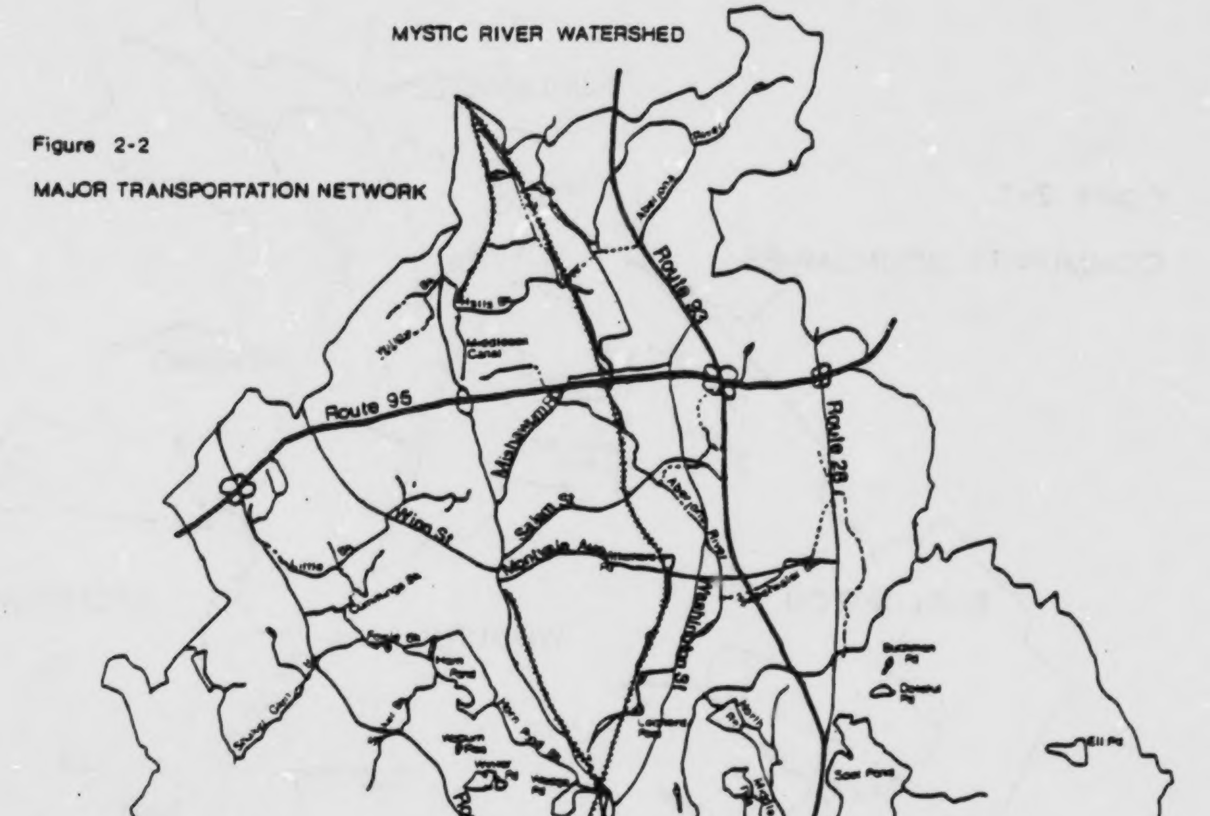
UPPER MYSTIC LAKE WATERSHED

Figure 2-1

COMMUNITY BOUNDARIES


WILMINGTON
River
Aberjona
READING
Willow Bk
Halls Bk
Middlesex Canal
BURLINGTON
WOBURN
STONEHAM
Aberjona River
Wittemore Pond
Sweetwater Brook
Little Brook
Cummings Brook
Fowle Bk
Shaker Glen Brook
Horn Pond
Horn Pond Bk
Sucker Bk
Woburn Res
Winter Pd
Wedge Pd
Leonard Pool
LEXINGTON
WINCHESTER
Lake
Upper Mystic
1
0
miles
ARLINGTON
MEDFORD

Mass. Department of Environmental Quality Engineering


Route 95
Route 93
Route 28
Route 3
Route 38
Route 2
Route 2A
Route 60
Washington St
Salem St
Montvale Ave
Winn St
Mishawum
Middlesex Canal
Aberjona River
Horn Pond
Horn Pond Bk
Spot Pond
Mystic Lk
Arlington Res
Mill Bk
Little River
Mystic River
Malden River
Fresh Pond
Payson Park Res
Ell Pd
Spot Pond
miles

MYSTIC RIVER WATERSHED

Figure 2-2

MAJOR TRANSPORTATION NETWORK

Mass Department of Environmental Quality Engineering

Reproduced from best available copy.

the glaciers of the Pleistocene Epoch, about 14,000 years ago (Cassidy, 1971).

The valley carved out prior to glaciation was buried by glacial outwash and till with a maximum recorded depth to bedrock within the Upper Mystic Lake Watershed of 165 feet (Resource Analysis, 1978). These extensive deposits are known as the Fresh Pond Buried Valley, one of four buried glacial valleys in the Boston area. The buried valley originates in the southern part of Wilmington and follows the course of the Aberjona River and the Mystic Lakes. It then continues south through Arlington and Cambridge. A westward tributary of this valley runs south through Horn Pond and southeast to join the main valley in Winchester (Cassidy, 1971). The Mystic Lakes, themselves, are also of glacial origin. As the glacier receded, ice blocks detached and melted forming lake basins or "kettle" lakes.

The U.S. Geological Survey (USGS) is in the process of preparing bedrock geology maps for the area (USGS, 1980b). A map of bedrock contours compiled from available sources was published as part of the Mystic River Basin Comprehensive Hydrology Study (Resource Analysis, 1978).

Surficial Deposits and Topography

The soils of the Upper Mystic Lake Watershed are, for the most part, remnants of glacial activity. Two types of deposits predominate, outwash and till. Outwash was deposited by glacial meltwater and consists of stratified and sorted sands, gravel and silts. Till, on the other hand, was deposited directly by the glaciers and is unsorted clay, sand, and gravel with cobbles and boulders. Though much less common, wetland areas are characterized by postglacial organic silts and peat. The lower portions of the Aberjona River are bordered by alluvial, sands, silts and organics (Resource Analysis, 1978).

When the last glacier retreated, late glacial streams formed the present day drainage network which has, since that time, been altered through natural processes and man's tampering (see Hydrology section). The gentle slope of the Aberjona stream bed, with a fall of 90 feet over its 8 mile length, reflects the overall gently rolling topography of the area. Scattered hills are found throughout the Watershed, many of which are bedrock outcrops. The most obvious outcrops are located south and northeast of Horn Pond. These include Horn Pond Mountain, with an elevation of 287 feet, Mt. Pisgah and Rag Rock Hill.

Maps of surficial geology are available from USGS for the upper portion of the Watershed (above Route 95). They are presently preparing such maps for the remainder of the Watershed (USGS, 1980a). A map of surficial deposits compiled from available sources was published as part of the Mystic River Basin Comprehensive Hydrology Study (Resource Analysis, 1978).

Lake Morphology

The Upper Mystic Lake is composed of three basins: two shallow northern basins and a main deep southern basin. The main basin has fairly concentric depth contours with a maximum depth of approximately 90 feet at its center.

The bathymetric map (see Figure 2-3) shows the main basin to be a typical glacial kettle hole. The adjoining northern basin, referred to as the lower forebay, is approximately 8 feet deep. The northernmost basin, referred to as the upper forebay, receives the Aberjona River and has a maximum depth of 6 feet. Morphometric data for Upper Mystic Lake are presented in Table 2-1. The total area of the lake is 167 acres with the main basin comprising 61% of the area (102 acres). The total volume is 273,000,000 cubic feet with the main basin accounting for 97% of the total volume. The lower forebay contains 1% of the total lake volume (3,800,000 cubic feet) and the upper forebay contains slightly more (5,200,000 cubic feet). The shoreline of the Lake is 14,719 feet (2.8 miles).

Hydrology

Precipitation. Historic precipitation data within the Upper Mystic Lake Watershed is limited. A permanent station in Reading has recorded daily data for 26 years and hourly data for 11 years. The Metropolitan District Commission (MDC) has maintained a daily recorder at Spot Pond, 2 miles northeast of the Upper Mystic Lake, since 1900. The most extensive record of hourly data maintained in the Boston area is the National Weather Service station at Logan Airport, about 9 miles southeast of the Lake, which has 43 years of record.

Table 2-1: UPPER MYSTIC LAKE MORPHOMETRIC DATA

	Total	Main Basin	Lower Forebay	Upper Forebay
Area (acres)	166	126	14.5	25.5
Maximum Depth (feet)	90	90	8	6
Mean Depth (feet)	38	48	6	5
Maximum Length (feet)		3450	490	899
Maximum Width (feet)		2150	621	572
Volume (cubic feet)	273,000,000	264,000,000	3,800,000	5,200,000
Main basin:				
0-30 feet		144,000,000		
30-60 feet		87,800,000		
60-90 feet		32,500,000		
Percent Volume		97%	1%	2%

Based on the 1981 Division of Water Pollution Control Bathymetric Map.

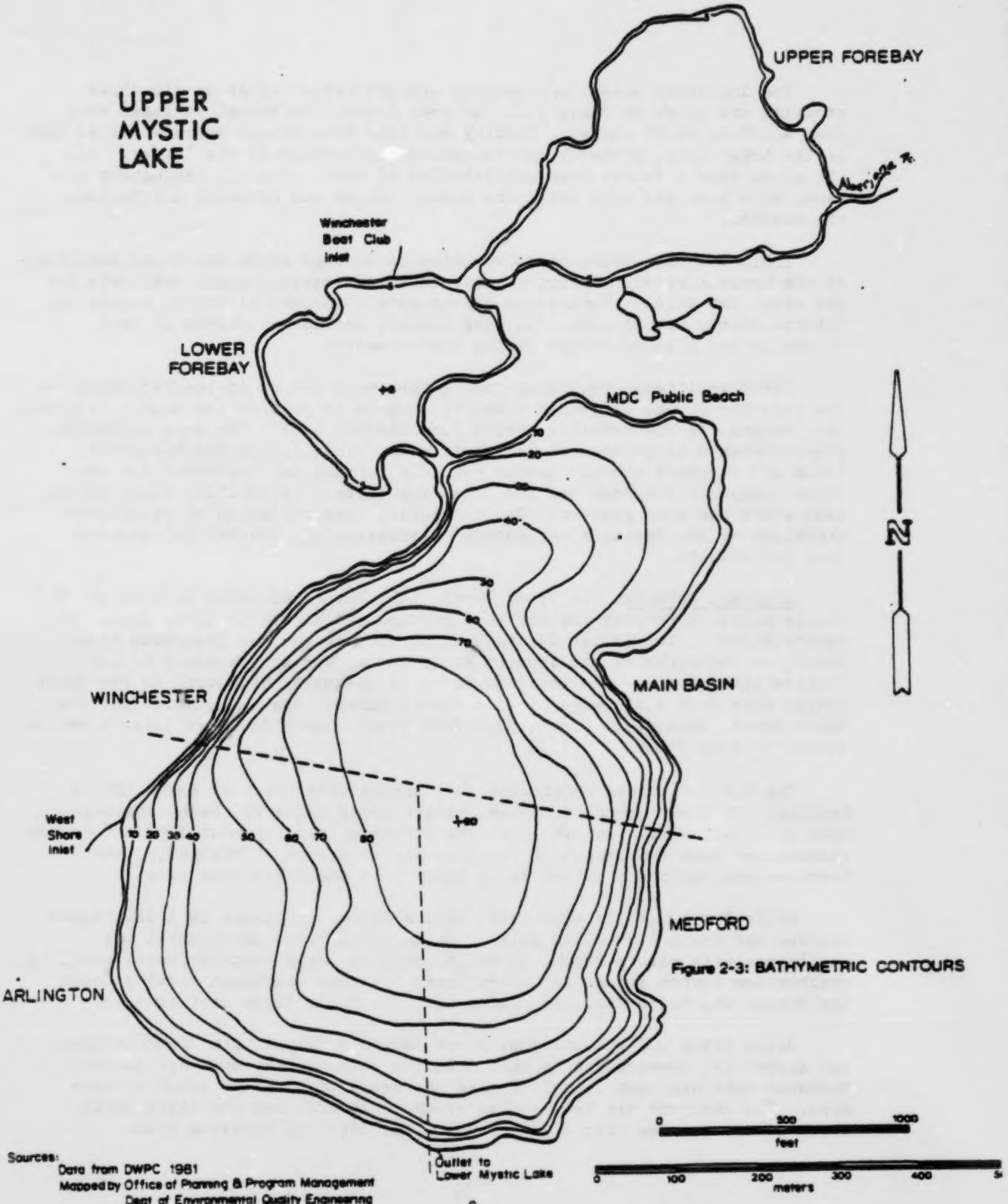

UPPER MYSTIC LAKE
UPPER FOREBAY
Aberjona R.
Winchester Boat Club Inlet
LOWER FOREBAY
+8
MDC Public Beach
10
20
30
40
50
60
70
N
MAIN BASIN
WINCHESTER
West Shore Inlet
10
20
30
40
50
60
70
80
+80
MEDFORD
ARLINGTON
Outlet to Lower Mystic Lake
0
500
1000
feet
0
100
200
300
400
500
meters
ISOBATHS IN FEET

Figure 2-3: BATHYMETRIC CONTOURS

Sources:
Data from DWPC 1981
Mapped by Office of Planning & Program Management
Dept of Environmental Quality Engineering

The long-term annual and monthly precipitation values at all three stations are shown in Table 2-2. As seen there, the annual averages vary from 41.50 to 46.87 inches. Reading and Spot Pond values compare better than do the Logan data, probably due to coastal influences at the latter. All the sites show a fairly even distribution of total rainfall throughout the year, with June and July being the driest months and November and December the wettest.

Table 2-2 also presents information on average storm depth and duration at the Logan station. Unfortunately, this information is not available for the other two sites. Variations demonstrate a pattern of short, relatively intense storms during June, July and August, and longer storms of less intensity but greater volume during winter months.

Three additional recording rain gauges were set up in the Watershed for the duration of the project's sampling program to provide the hourly rainfall data needed for the modeling effort (see Chapter 3.0). The data collected demonstrated a large spatial variability in rainfall over the Watershed. Table 2-3 presents monthly totals for July, August and September for our three temporary stations and two long-term sites. Variability found within each storm was even greater. Daily rainfall data collected by volunteers, organized by the Mystic River Watershed Association, further collaborated this variability.

Drainage Network. The Upper Mystic Lake Watershed, with an area of 28.0 square miles, comprises the northern portion of the Mystic River Basin (61.9 square miles). The latter is bordered on the west by the Shawsheen River Basin, on the north by the Ipswich River Basin, and on the south by the Charles River Basin. The Aberjona River is the major tributary to the Upper Mystic Lake with a drainage of 25.6 square miles. Its tributaries include Halls Brook, Sweetwater Brook, Horn Pond Brook, and Whittemore (also known as Walker's) Pond Brook.

The Aberjona River originates in a marshy area north of Route 129 in Reading. It flows south, branches, passes under Route 93, meets drainage from two small ponds just south of the Woburn-Wilmington boundary, and is now channelized down the length of Commerce Way in Woburn. Originally, the branches met again and joined Halls Brook just above Mishawum Lake.

Halls Brook and its tributary, Willow Brook, originate in a Burlington wetland and drain 2.9 square miles. Halls Brook flows north until its confluence with Willow Brook, at which point it turns east-northeast until it reaches New Boston Street in Woburn where it turns southeast, flowing under the Boston and Maine Railroad tracks into the Halls Brook storage area.

Halls Brook and the Aberjona River formerly flowed into Mishawum Lake, but industrial development in that area has altered that drainage pattern. Mishawum Lake has been largely filled and replaced by Halls Brook storage area. The Aberjona has been routed around this area and now joins Halls Brook at the storage area outlet immediately north of Mishawum Road.

Table 2-2: LONG TERM PRECIPITATION CHARACTERISTICS

Month	Reading		Spot Pond		Logan International Airport				
	Average Precipitation in Inches *	Average Precipitation as % total yearly	Average Precipitation in Inches	Average Precipitation as % total yearly	Average Precipitation in Inches	Average Precipitation as % total yearly	Average Storm Depth (inches)	Average Storm Duration (hours)	Average Storm Intensity Inches/hours
January	4.16	9.1	4.07	8.7	3.64	8.8	0.33	8.4	0.031
February	3.56	7.8	3.84	8.1	3.38	8.1	0.35	7.5	0.033
March	4.28	9.4	4.26	9.1	3.82	9.2	0.34	7.2	0.033
April	3.77	8.2	3.95	8.4	3.55	8.6	0.31	6.6	0.037
May	3.73	8.2	3.90	8.3	3.25	7.8	0.27	5.6	0.038
June	3.00	6.6	3.15	6.7	3.12	7.5	0.25	4.1	0.058
July	2.80	6.1	3.14	6.7	3.15	7.6	0.25	3.6	0.067
August	3.71	8.1	3.80	8.1	3.61	8.7	0.31	4.1	0.067
September	3.67	8.0	3.49	7.4	3.22	7.8	0.37	5.2	0.053
October	3.79	8.3	3.69	7.9	3.24	7.8	0.36	6.2	0.043
November	4.67	10.2	4.95	10.6	3.84	9.2	0.39	6.6	0.042
December	4.57	10.0	4.65	10.0	3.69	8.9	0.44	8.7	0.038
	45.71	100.0	46.87	100.0	41.50	100.0			

* 30 year Normal: 1951 - 1980

Sources: Camp, Dresser and McKee, Inc./Resource Analysis, 1980a.
Lautzenheiser, 1982.

Table 2-3: SPATIAL RAINFALL VARIABILITY

	Cumulative Rainfall (inches) - 1981		
	July	August	September
NURP GAUGES			
Winchester	3.76	1.90	3.26
Stoneham	4.64	1.98	2.9
Burlington	3.98	1.06	3.55
Long-term Stations			
Reading	5.39	1.25	4.18
Spot Pond	4.22	1.64	2.25

Shortly after leaving the industrial park, the river passes under Route 95 and is culverted for a distance of 800 feet through another industrial area near Olympia Avenue. The Aberjona enters a marshy area, eventually dissipating into a small swamp upstream of Cedar Street near Washington Street. Passing Cedar Street, it once more meanders through marshlands before entering Burbank Pond. In previous years, the Aberjona was impounded and Burbank Pond served as a cranberry bog. Now the flow is restricted only during the winter to provide ice skating. A defined channel is maintained while passing under Washington Street and Montvale Avenue, shortly after which Sweetwater Brook joins the Aberjona from the east.

Sweetwater Brook, which has a predominantly urban drainage area of 2.3 square miles, rises in a marshy area next to Main Street in Stoneham. It flows south and then is culverted for about 2,000 feet. After leaving the culvert, Sweetwater Brook flows southwest to just east of Route 93 where it is culverted for the rest of its length.

Below Sweetwater Brook the Aberjona River continues flowing to the south for slightly more than one-half mile. It then turns abruptly and crosses under Garfield Street where two small dams are found, one before and one after the crossing. The Aberjona continues to travel south for approximately one-quarter mile flowing over another small dam before entering a long, narrow impoundment upstream of Swanton Street. Downstream of Swanton Street the Aberjona travels in an open channel a few hundred feet until reaching Winchester High School's athletic field, which was once Aberjona Pond. The pond has been filled and the Aberjona flows through three culverts beneath the field.

Below the athletic field, Horn Pond Brook, which has a total drainage area of 10.0 square miles, joins the Aberjona River. The outer parts of the Horn Pond Brook Watershed are drained by Shaker Glen, Cummings and Sucker Brooks. Cummings Brook and Shaker Glen Brook rise in marshy areas to the north and west of Horn Pond, respectively. Cumming's Brook meanders in a southerly direction, while Shaker Glen Brook generally flows northeast until its confluence with Cummings Brook to form Fowle Brook. Fowle Brook flows due east where it empties into Horn Pond. Sucker Brook rises to the south and flows northeast to Horn Pond.

Horn Pond covers an area of roughly 120 acres and is used for recreation and as water supply recharge for the City of Woburn's wells. In recent years, its capacity has been increased by raising its normal water surface approximately six feet. Horn Pond flows over a weir into Horn Pond Brook, which then flows in a southeasterly direction through Wedge Pond to the Aberjona River. Below its confluence with Horn Pond Brook, the Aberjona enters Judkins Pond and Mill Pond in Winchester Center. The outlet of Mill Pond is a semi-circlular step spillway with a fall of approximately six feet. The Aberjona continues south past the U.S. Geological Survey (USGS) flow gauging station. As the Aberjona nears its end, it makes a final bend to the west, gaining depth and width as it enters the Upper Mystic Lake.

The USGS has recorded continuous flow rates at the Aberjona River gauge (01102500) since 1939. The average flow rate (41 years of record) is 27.5 cubic feet per second (cfs) with a maximum flow of 1,330 cfs on January 25, 1979, and a minimum daily average of .25 cfs on October 10, 1950 (USGS, 1980c). Flow data for other points of the Watershed are limited. The State Division of Water Pollution Control took flow measurements at six points along the Aberjona and on three tributaries during June and August 1973 (Mass. WRC, 1974b). As part of this project, flow data were collected for the storm events sampled (see Chapter 3.0). The USGS conducted flow time-of-travel studies on the Aberjona in October 1973 and March 1974 at low and medium flows, respectively. Results showed that at low flows (3 cfs) it took 135 hours for water to travel from Mishawum Road to the Lake inlet and that at 45 cfs it took only 20 hours to travel the same distance (USGS, 1980e).

An unusual flow situation has been recorded along the Aberjona where the flow rate has decreased in the downstream direction. Two possible causes of this condition have been identified. Withdrawal of groundwater for municipal and industrial use from well fields adjacent to the river may cause the drawdown effect (Mass. WRC, 1975; Warrington, 1973). Infiltration loss to underlying sewer lines has also been suggested (Warrington, 1973). Several of the wells have been closed recently, but the impact of that action on the flow situation has not been determined.

In addition to the Aberjona, there are two inlets to the Lake (see Fig.2-2). The West Shore Inlet which drains 480 acres and the Boat Club Inlet draining 495 acres. Estimated annual flows for each are 0.24 and 0.52 cfs, respectively; summer average estimates are given in Table 2-4. The remaining Watershed area, 540 acres, drains directly into the Lake by overland runoff with an estimated average annual flow of 0.53 cfs (CDM, 1982).

Additional information on Aberjona flow characteristics can be found in the Mystic River Basin Comprehensive Hydrology Study (CDM, 1981a) and the USGS Hydrologic Atlas H-589 (USGS, 1980e).

Groundwater. Groundwater is the subsurface water found beneath the water table in saturated soils and geologic formations. Groundwater in Upper Mystic

Lake Watershed is found in the large valley fill aquifer known as the Fresh Pond Buried Valley as described earlier. The transmissivity of the aquifer, or permeability multiplied by aquifer thickness, is an indicator of how much water can be drawn from the ground. The Mystic aquifer varies from high transmissivity under the Aberjona River (greater than 4000 ft^2/day), with a potential well yield of greater than 300 gallons per minute (gal/min), to a low transmissivity of less than 1400 ft^2 /day or a potential well yield of less than 100 gal/min. Most of the Watershed's aquifer tends to be of lower transmissivity (USGS, 1980e).

Lake Water Budget. Determining the water budget of a lake is essential to assessing the physical, chemical and biological processes of the lake system. The complexity of the hydrologic cycle, however, makes it difficult to calculate a definitive water budget. Our data allow a rough estimate which is sufficient for our purposes.

The water budget is calculated using basic conservation of mass hydrological relationships in which a change in water storage equals inputs from all sources less water loss. Water coming in from precipitation, surface drainage and groundwater is balanced by outflow, outlet discharge, infiltration to groundwater and evaporation. Each of these sources and losses varies seasonally and is governed by the morphology of the lake basin, its drainage area, or watershed climate. The water budget for Upper Mystic Lake was calculated on an annual average flow and summer average flow basis.

The major tributary to the Lake is the Aberjona River with an annual average flow to the Lake of 27.5 cfs. The Boat Club Inlet (0.52 cfs), West Shore Inlet (0.24 cfs) and direct drainage to the Lake (0.53 cfs) are smaller but significant given their nutrient contributions. Estimated groundwater flow accounts for 5% of the annual flow to the Lake and precipitation on the Lake surface accounts for 3% based on 41 inches per year.

The major loss from the Lake is the discharge at the outlet dam to the Lower Mystic Lake. Due to the dam structure, outflow measurement was not possible, so an annual estimate was calculated as 22.4 cfs, assuming a constant Lake volume. This comprises 97% of the water loss of the Lake. Annual evaporation losses based on monthly rates comprised the remaining water loss of the Lake (3%). The actual evaporation rate is higher than this given the evapotranspiration of the excessive aquatic weed growth present in the Lake, but is difficult to estimate. Given the rough estimation of this budget, monthly evaporation rates based solely on air and water temperatures are sufficient.

Based on the above sources and losses and annual average flows, and assuming a constant volume, Upper Mystic Lake has a flushing rate of 3.5 times a year (retention time of 104 days). The two forebays have a combined retention time of 8 days. In the summer, hydraulic conditions change with the main basin thermally stratifying, isolating the hypolimnion, and thus reducing the volume involved in circulation (as described in section 6.1). Inputs to the Lake are also generally less. Based on these summer conditions, the flushing rate drops to 2.3 times a year or less than once a summer. Likewise, the retention time in the forebays is extended to approximately

19 days. This time lag of over two weeks allows some settling and filtering of river water before entering the main basin, especially since the forebays are filled with aquatic vegetation during this time which serves as a filter in many respects.

Under summer storm conditions tributary flows can increase considerably in a matter of hours shortening the retention time in the forebays. As demonstrated during the circulation study, when Aberjona flows jumped from 8 cfs to 62 cfs in 6 hours, river water passed through the two forebays in less than two days. Table 2-4 summarizes water budget data.

Water Movement. The hydrodynamics or water movements of the Upper Mystic Lake are important in terms of pollution transport and distribution. Using a series of circulation studies, conducted under this project, and temperature data, an understanding of the Lake's hydrodynamics is possible.

The purpose of the circulation studies was to trace the flow patterns within the Lake and determine whether Aberjona River water becomes mixed with Lake water or tends to short circuit through the forebays flowing directly to the main basin. Flow regimes in the vicinity of the MDC public beach are of particular concern because of the impact of upstream bacteria sources on swimming water quality. Bacteria samples were taken in conjunction with the circulation study and will be discussed in Chapter 6.0.

No short circuiting in the forebays occurred during the dry or wet weather flow conditions tested during the circulation study. In particular, it was shown that the effect of Aberjona flow on Lake hydraulics is generally limited to the upper forebay. Aberjona flow extends into the Lake with minimal dispersion a distance proportional to the flow rate and then becomes completely mixed. For example, under low flow conditions (5 cfs), typical of dry summer days, Aberjona flow only moved 35 feet into the upper forebay before complete mixing. Whereas, under high flow conditions (60 cfs), typical of spring flows, Aberjona River water moved over 600 feet into the upper forebay before mixing.

A second factor influencing the direction of water movement in the Lake is wind. As demonstrated during the low flow circulation study, dye injection at the Aberjona inlet and between the lower forebay and main basin moved in an upstream direction, against the expected direction of flow. This upstream movement was due to a prevalent north wind. Once the water reaches the main basin, winds tend to hold it in the northern end. This can be seen in Figure 2-4. In Figure 2-4a and 2-4b, injected dye flowed in the expected southern direction towards the Lake outlet. In Figure 4c, twenty-two hours following the dye injection a moderate south to southeast wind influenced the direction of movement, trapping the dye in the northern end of the main basin. Wind and resulting wave turbulence tended to carry the dye along the shorelines. The discrete dye slug near the southwest shore is probably a result of localized wind currents due to basin topography.

A third factor influencing water movement is temperature. Temperature is the primary regulator of water density: warmer waters are less dense, thus lighter than cooler waters. Incoming water of a specific density tends to seek out waters at a depth of similar density as usually determined by temper-

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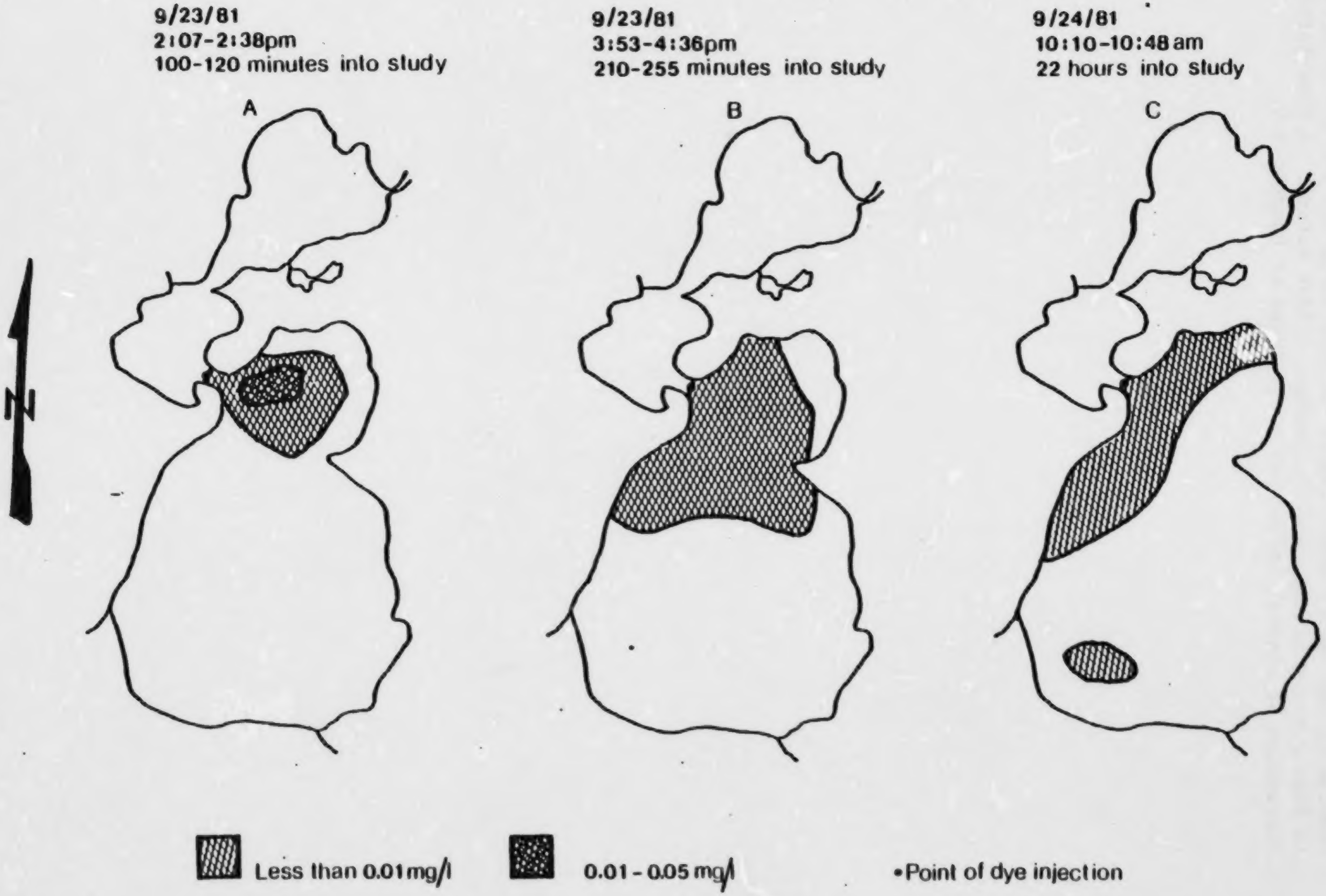
Table 2-4: UPPER MYSTIC LAKE WATER BUDGET

Inputs to the Lake	Annual Averages (cfs)	Summer Averages (cfs)
Aberjona River	27.5	11.1
Yacht Club Inlet	0.52	0.37
West Shore Inlet	0.24	0.13
Direct Drainage	0.53	0.34
Precipitation	0.79 (41 in./yr.)	0.74
Net Groundwater	1.5	minimal
Losses from the Lake		
Outlet at dam	22.4	3.2
Evaporation	0.73	1.29
Annual		
Retention time-entire lake	104 days	Based on annual flows, assuming mixed system
Flushing rate	3.5 times/yr.	
Retention time-both forebays	8 days	
Retention time-upper forebay	4 days	
Summer		
Retention time-entire lake	158 days	Based on summer flows and assuming isolated, non-circulating hypolimnion.
Flushing rate	0.6 times/summer	
Retention time-both forebays	19 days	

Figure 2-4: WIND INFLUENCES ON LAKE CIRCULATION



9/23/81
2:07-2:38pm
100-120 minutes into study

9/23/81
3:53-4:36pm
210-255 minutes into study

9/24/81
10:10-10:48 am
22 hours into study

A
B
C
N
▨ Less than 0.01mg/l
▩ 0.01 - 0.05 mg/l
•Point of dye injection

ature. This was seen in the main basin where water entering the main basin remains in the warmer upper region flowing along the surface to a depth of 10 feet and not mixing with the deeper, colder waters. A more detailed discussion of thermal influences is included in Chapter 6.0.

2.2 GROWTH AND DEVELOPMENT

Historical

Many changes have taken place in the Upper Mystic Lake Watershed since the Massachusetts Bay Colony was founded in 1630. The area was originally settled by the Algonquin Indians. It is believed that these Indians are responsible for the name of the Mystic Lakes, despite its change from the original "Missi-Tuk". Translated, these words mean "great" and "a river whose waters are driven by waves" (Cassidy, 1971). This appropriately described the lakes which, at that time, were tidal.

Farming was the primary land use in the Watershed for many years until transportation channels were opened in 1803 when the Middlesex Canal was completed. The 27 mile-long waterway, spanning from Charlestown to Lowell, encouraged the transition from agriculture to industry. In 1835, the opening of the Boston and Lowell Railroad induced further industrial growth, but the once extensively used Middlesex Canal became obsolete (Resource Analysis, 1978). The canal was kept in operation until 1853 (Middlesex Canal Association, Inc., 1971).

Many chemical companies and other industries were established along the tracks of the railroad, particularly in the upper part of the Watershed, the first being the Merrimack Chemical Company in Woburn in 1853. Tanners, shoe manufacturers, and food processors were among the other major industries located in the area at this time. Some of these industries used scrap materials from Boston slaughterhouses.

The next big change in the Watershed came in 1864 when the dam between the Upper and Lower Mystic Lakes was built. This allowed the Upper Mystic Lake to be maintained as a freshwater lake since the effects of the tides were halted by the dam. The Upper Mystic Lake then became a source of drinking water. Approximately 30 million gallons of water per day were pumped from the Lake to the College Hill Reservoir in Medford. From there the water was distributed to Charlestown and later to Somerville (Cassidy, 1971). This use of the Lake continued until the 1890's when gelatin, dyes, and tanning wastes from the Aberjona River polluted the Lake, stopping its use not only as a water supply source, but as a recreational area too.

Throughout the early 1900s the quality of the Lake oscillated. Despite periodic bathing prohibitions, several recreational facilities were constructed along the Lake. The Metropolitan Park Commission acquired 2½ miles of shoreline and developed a parkway between Winchester and Medford and a recreational facility at Sandy Beach. Also, private boat clubs were established along the Lake.

The temporary closing of industries during World War I (1914-1918) helped to improve the Lake's water quality; however the polluting industries continued to function until the 1930s when the lure of cheap labor and modern equipment elsewhere prompted the shoe and textile industries to leave Massachusetts.

With the closing of the Boston stockyards, many chemical companies were forced to shut down too.

The loss of these industries encouraged communities in the northern portion of the Watershed to attract new "high technology" firms. Problems developed when these companies began to establish themselves on the same land previously used by the tanning and chemical companies. Recently, old waste deposits were uncovered and have been determined to be a health hazard. More will be said about this problem in Chapter 5.0.

Present and Future

Population and Land Use. In the past two decades intensive urbanization has taken place in most areas of the Watershed. All communities except for Medford showed substantial increases in their populations between 1950 and 1970, a trend which is expected to continue at a slower rate in the future. Table 2-5 shows the populations in the Watershed as of 1975, the change in population since 1950, and the projected growth rates.

Land use in the Watershed has reflected these population changes with single family homes being the predominant form of development (CDM, 1981a). Industrial and commercial growth followed the changing economic trends by moving away from water-intensive practices toward a technical service-oriented economy. The rapid development of land along major highways, such as Routes 95 and 93, is evidence of this transition.

This pattern of growth is expected to continue, especially in the northern sections of the Watershed where more undeveloped land exists. Table 2-6 presents land use data for eight areas of the Watershed. The Mystic River Comprehensive Hydrology Study conducted by CDM (1981a) included the estimation of future land development within the Watershed. These projections were based on data from the Metropolitan Area Planning Council (1977a), the Eastern Massachusetts Metropolitan Area Study (US Army, 1975b), and the community planning departments. Two degrees of development were considered — Case 1 where approximately half the developable land will be used; and Case 2 where all the developable land will be employed. Also, maps showing which areas of the watershed likely to be developed under these two cases can be found in the CDM report (1981a).

Open Space and Recreation. The increase in the amount of developed land has led many communities to purchase land adjacent to surface waters to maintain it for conservation and/or recreational purposes. This also encourages the use of these surface waters for similar purposes. In order to obtain current surface water use information, a questionnaire was sent to local officials. Table 2-7 lists the results, making reference to the surrounding open space and recreational facilities shown on Figure 2-5. Local views on future uses of these areas are discussed in Chapter 4.0.

Within the Watershed, the Upper Mystic Lake and Horn Pond are most intensely used for recreational purposes. The eastern shoreline of Upper Mystic Lake is owned by the Metropolitan District Commission (MDC) which maintains the park and beach facilities located at the northern end of the

Table 2-5: COMMUNITY POPULATION CHANGES IN THE UPPER MYSTIC LAKE WATERSHED

Community	1975* Population	Percent Change 1950-1970	Percent Change 1975-1995
Arlington	50,300	20.7	0.2**
Burlington	24,400	76.3	16.8
Lexington	32,500	83.9	10.8
Medford	60,800	- 2.6	3.6
Reading	23,700	60.9	28.7
Stoneham	22,000	56.7	11.4
Wilmington	17,500	143.0	7.1
Winchester	22,700	43.6	8.4
Woburn	35,200	82.5	18.2

* Data from 1980 census was not obtained but should now be available.

** Arlington's population has actually declined slightly in recent years.

Source: Resource Analysis, 1978.

Table 2-6: CURRENT LAND USE BY SUB-WATERSHED*

Sub-watershed	Percent Land Use: Open Space	Percent Land Use: Residential	Percent Land Use: Commercial/ Industrial
Mishawum	38%	43%	19%
Sweetwater	15%	80%	5%
Unnamed Tributaries	19%	69%	12%
Muraco	30%	60%	10%
Horn Pond	28%	65%	7%
Highland	30%	60%	10%
Direct Drainage (Aberjona)	40%	51%	9%
West Shore	70%	25%	5%
Boat Club	10%	60%	30%
Direct Drainage (Lake)	13%	63%	24%

Source: CDM, 1982

* See Figure 3-11 for sub-watershed delineation.

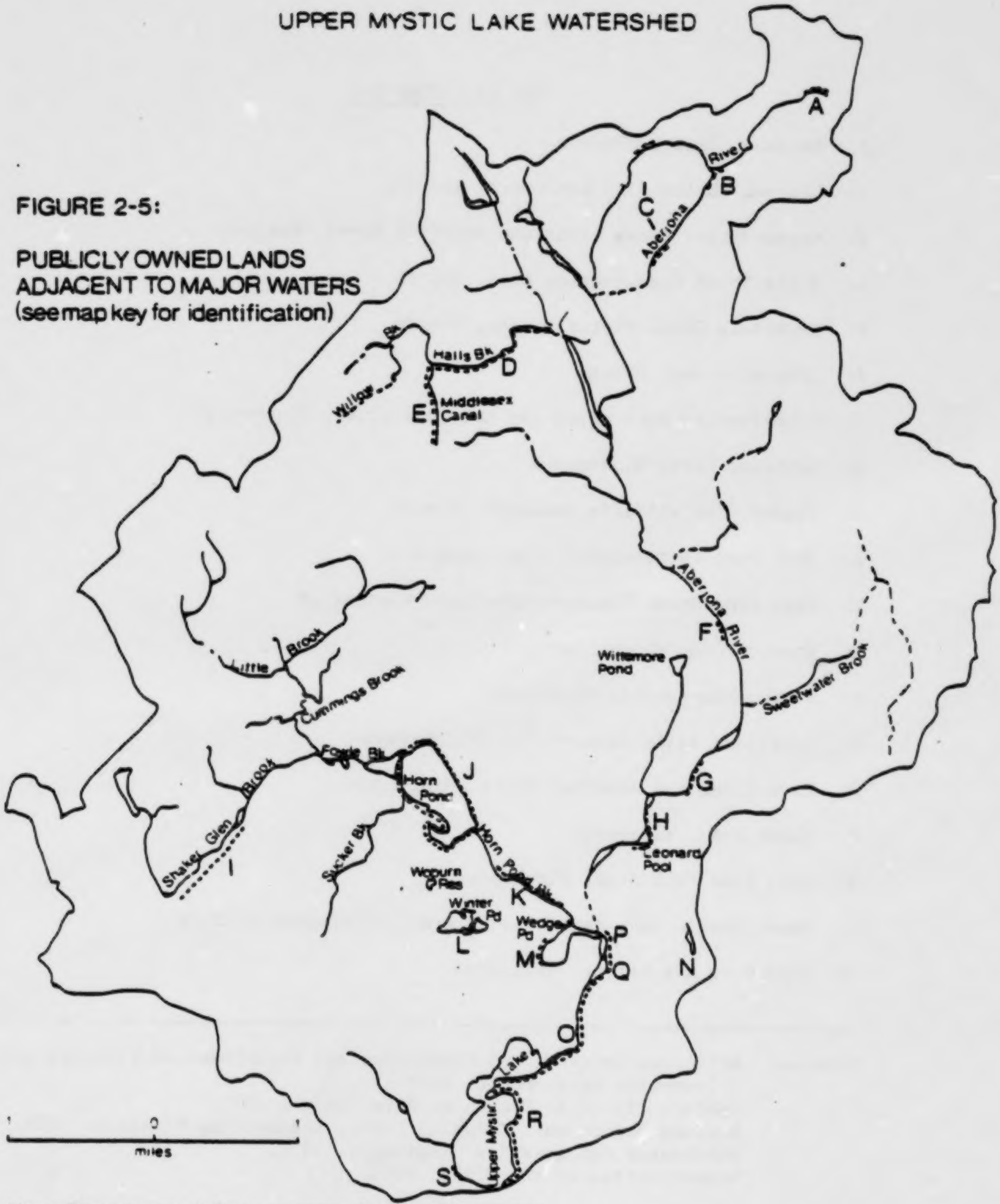
Table 2-7: USES OF MAJOR WATER BODIES

Surface Water Area	Use(s)	Reference to Figure 2-5
Aberjona River Headwaters (to Route 128)	Conservation Area Flood Control Park or Playground Skating	A, B, C
Halls Brook	Conservation Area Flood Control	D
Middlesex Canal	Flood Control Historical Area Non-Motor Boating Park or Playground Skating Warm Water Fishing	E
Aberjona River (Route 128 to Sweetwater Brook	Conservation Area Flood Control Skating	F
Aberjona River (Sweetwater Brook to Wedge Pond)	Conservation Area Flood Control Park or Playground	G
Leonard Pool	Park or Playground Skating Swimming	H
Shaker Glen Brook	Cold Water Fishing Conservation Area Flood Control Skating Warm Water Fishing	I
Horn Pond	Cold Water Fishing Conservation Flood Control Motor Boating Non-Motor Boating Skating	J
Horn Pond Brook	Conservation Area Flood Control	K
Winter Pond	Non-Motor Boating Skating Warm Water Fishing	L
Wedge Pond	Cold Water Fishing Flood Control Non-Motor Boating Park or Playground Skating Swimming Warm Water Fishing	M
Long Pond	Conservation Area Skating	N
Aberjona River (Wedge Pond to Upper Mystic Lake)	Conservation Area Flood Control Park or Playground	O
Judkins Pond	Conservation Area Park or Playground Warm Water Fishing	P
Mill Pond	Conservation Area Flood Control Park or Playground Warm Water Fishing	Q
Upper Mystic Lake	Conservation Area Flood Control Non-Motor Boating Park or Playground Skating Swimming Warm Water Fishing	R, S

UPPER MYSTIC LAKE WATERSHED

FIGURE 2-5:

PUBLICLY OWNED LANDS ADJACENT TO MAJOR WATERS (see map key for identification)


A
River
B
C
Aberjona
Halls Bk
D
Willow Bk
E
Middlesex Canal
Aberjona River
F
Wittemore Pond
Sweetwater Brook
Little Brook
Cummings Brook
Fowle Bk
J
Horn Pond
Shaker Glen Brook
I
Sucker Bk
Woburn Res
Wynter Pd
L
Horn Pond Bk
K
Wedge Pd
M
P
Q
G
H
Leonard Pool
N
O
Lake
Upper Mystic
R
S
1
0
1
miles

Mass. Department of Environmental Quality Engineering

KEY TO FIGURE 2-5

A: Kurchian Woods, Reading

B: Linnaea Thelin Bird Sanctuary, Reading

C: Conservation Areas along the Aberjona River, Reading

D: Halls Brook Conservation Area, Woburn

E: Middlesex Canal Historic Area, Woburn

F: Cranberry Bog, Woburn

G: Conservation Area along the Aberjona River, Winchester

H: Davidson Park, Winchester

I: Shaker Glen Wildlife Wetlands, Woburn

J: Horn Pond Recreational Area, Woburn

K: Horn Pond Brook Conservation Area, Winchester

L: Winter Pond, Winchester

M: Palmer Playground, Winchester

N: Middlesex Fells Reservation, Winchester

O: Park along the Aberjona River, Winchester

P: Eliot Park, Winchester

Q: Mill Pond Park Area, Winchester

R: Upper Mystic Lake Recreational Area, Winchester/Medford

S: Window on the Mystic, Arlington

Sources: Arlington Conservation Commission and Department of Planning and Community Development, 1979.
Medford Office of Community Development, 1977.
Reading Department of Public Works, Engineering Division, 1976.
Winchester Conservation Commission, 1977.
Woburn Office of the Mayor, 1979.

Lake. During the summer months approximately 1,500-2,000 people on weekends, and 600-800 individuals on weekdays typically use this area (Mass. MDC, 1979b). The park is also used year-round by people seeking a quiet place to read, walk, or partake in other activities. The western shoreline is primarily privately owned, except for a small area of open space called Window-on-the-Mystic which is owned by the Arlington Conservation Commission.

Private recreational facilities on the Upper Mystic Lake include three boat clubs. The Winchester Boat Club is located on the lower forebay, and the Medford Boat Club and Tufts University Club are located at the southwest and southeast end of the main basin, respectively. Between these facilities and other privately owned docks, many individuals are able to enjoy non-motor boating on the Lake. Motor boating is not allowed.

Another major recreational use of the Upper Lake is fishing. In the past, the Lake supported cold water game fish. The Division of Fisheries and Wildlife stocked the Lake with trout until 1970 when water quality conditions prevented the survival of the cold water species (Jason M. Cortell, 1970). Currently, the Lake supports a popular warm water fishery.

Horn Pond is contained in an area known as Horn Pond Mountain. The City of Woburn owns most of this land which includes parks and playgrounds. Water-related recreational activities are similar to those for the Upper Mystic Lake except that Horn Pond supports cold water game fish and swimming is not allowed. It is the only water body in the Watershed which is still stocked with trout by the State Division of Fisheries and Wildlife. Horn Pond is also used to recharge Woburn's drinking water wells.

Other surface waters within the Watershed support limited water activities. Shaker Glen Brook and Judkin's Pond support fisheries and are adjacent to publically owned lands. Part of the land along Shaker Glen Brook is owned by the Woburn Conservation Commission and has been designated as a wildlife conservation area. The land around Judkin's Pond is owned by the Town of Winchester.

In addition to the Upper Mystic Lake, swimming is permitted in Wedge Pond and Leonard Pool. Wedge Pond is bordered by Palmer Playground on its southern shore, while Leonard Field is adjacent to the eastern side of Leonard Pool. Leonard Pool has an outlet to the Aberjona River but is filled using well water. Both of these recreational areas are owned by the Town of Winchester.

Within the Upper Mystic Lake Watershed, public lands abut other water resources. Some of these areas are designated as conservation sites, while others are parks, playgrounds, or undeveloped open space. Improvements in the water quality of surface waters adjacent to these lands, especially the parks and playgrounds, may allow greater recreational benefits.

The conservation areas within the Upper Mystic Lake Watershed are primarily owned by city or town conservation commissions. The only state-owned conservation land, the Middlesex Falls Reservation, is managed by MDC. Only a small portion on the western edge of the reservation is included in the Watershed but the entire area serves as an environment for the protection of wildlife in a natural habitat. Other major locations which are preserved for this type of protection are Kurchian Woods and Linnaea Thelin Bird Sanctuary in Reading, Shaker Glen Brook and the Cranberry Bog conservation areas in Woburn, and Window-on-the-Mystic in Arlington.

Remnants of Middlesex Canal in the Watershed are a designated historic area. After being abandoned for over a century, parts of the canal were restored by the Middlesex Canal Association in an effort to preserve its historical and recreational value. A linear park was developed along the canal in North Woburn where horse-drawn barges take tourists on excursions up and down the canal in the summer months.

Water Supply. Another concern in urban areas is water supply planning, particularly with the recurring drought conditions experienced in many areas of the Commonwealth. A study conducted by the Metropolitan Area Planning Commission (1977a) indicated that the demand for water in the Watershed was at or near capacity (Table 2-8). Any large increases in demand which would be likely to accompany additional urbanization may require an expansion of the existing water supply systems.

In the Watershed water supplies are taken from both ground and surface waters. Four communities regularly receive water from MDC which distributes water from the Quabbin Reservoir located in western Massachusetts. Three towns employ wells, and two use surface water reservoirs. Table 2-8 shows the various water supply sources for the communities in the Watershed.

Table 2-8: MUNICIPAL WATER SUPPLIES

Community	Daily Safe Yield* (mgd)	1975 Daily Average Demand (mgd)	Type of Supply Used
Arlington	6.8	6.65	MDC
Burlington	7.66	2.90	Groundwater, Shawsheen River
Lexington	4.5	4.59	MDC
Medford	8.1	8.29	MDC
Reading	5.9	2.6	Groundwater
Stoneham	3.4	3.53	MDC
Wilmington	7.1	2.7	Groundwater
Winchester	2.88	2.05	Groundwater; MDC; North, South, and Middle Reservoirs (Middlesex Fells Reservation)
Woburn	13.2	4.45	Groundwater; Horn Pond for Well Recharge; MDC in Emergencies

* For communities served by the MDC safe yield is based on MDC allocation.

Sources: Massachusetts EOEA, 1978; Resource Analysis, 1978.

3.0 METHODOLOGY

The purpose of this chapter is to briefly describe the methodology of the Upper Mystic Lake Urban Runoff Project, including both the technical components and the coordination of state, regional and local interests. Additional information detailing the technical methods is presented in consultant reports as listed in Chapter 1.0 and referenced in this chapter.

3.1 TECHNICAL STUDY DESIGN

As discussed in Chapter 1.0, the major objectives of this project were:

- to identify the quantity and quality characteristics of urban runoff in the Upper Mystic Lake Watershed;
- to assess the impact of urban runoff on the Aberjona River and Upper Mystic Lake; and
- to recommend controls to achieve water quality goals in the Upper Mystic Lake.

Meeting these objectives required analyzing the Watershed's response to a number of complex physical, chemical and biological processes. In the Upper Mystic Lake Watershed, as in many urban areas, this task is complicated by the presence of a number of pollution sources and the fact that observed water quality conditions are the response to the combined pollutant input. Given the complexity of the water resource system in the Watershed, the technical analysis was broken down into five study elements or sub-systems.

(1) Precipitation,
(2) Pollutant Generation,
(3) In-stream Transport and Conditions,
(4) In-lake Conditions, and
(5) Control Evaluation.

The specific goals established for each element are listed in Table 3-1. The data collection and analysis components of each of these study elements will be discussed below.

Two additional elements were included in the original workplan: a transfer application of the models developed to another watershed, and a control implementation monitoring program. These elements were not completed due to budgetary and time constraints.

3.2 MONITORING PROGRAM

The monitoring program was designed to collect the information required for each study element. The requirements were initially defined by DEQE urban runoff staff, the data analysis and field consultants, Camp Dresser & McKee, Inc., and Environmental Design and Planning, Inc., respectively. As the program proceeded, requirements were reevaluated and changes were made as needed.

Both dry and wet weather conditions were monitored. The decision to sample a storm event was based on several criteria:

(1) significant runoff from an event was needed to adequately characterize its quality, with minimum requirements being at least 0.1 inches of depth and one hour of runoff;

(2) at least two days without rainfall before the event;

(3) the events sampled had to be representative of the full range of annual storm events; and

(4) the majority of sampling stations needed to be operational throughout the event.

Tables 3-2 through 3-4 summarize the monitoring program as described in more detail below.

Precipitation

Two levels of precipitation data were required: (1) long-term characteristics which were developed using established stations (described in section 2.1), and (2) accurate data on the quantity and distribution of rainfall throughout the Watershed for each storm event monitored.

Three hourly rainfall recorders were installed and maintained by DEQE urban runoff staff in Winchester, Stoneham and Burlington as shown in Figure 3-1. The fourth hourly station shown there is a permanent station maintained in Reading by New England Climatic Service. Daily data were collected by volunteers organized by the Mystic River Watershed Association to provide additional information on variability throughout the Watershed.

Stormwater

Stormwater was monitored by the field consultants at two stormwater collection system outfalls, referred to as end-of-pipes (EOPs), to determine

22

Table 3-1: WORK ELEMENT GOALS

1. PRECIPITATION

a. determine the statistical characteristics of the precipitation process in the study area;

b. use the results of the statistical analysis above to develop the input rainfall data for the simulation models used in subsequent components of this study.

2. POLLUTANT GENERATION

a. identify the characteristics of urban runoff;

b. perform a preliminary assessment of the importance of the pollutant load borne by urban runoff in relation to other pollution sources;

c. evaluate the practicality of applying data gathered in this study to similar urban environments in other parts of the nation;

d. verify the computer simulation models developed in this and subsequent portions of the project.

e. provide an analytical tool - the STORM computer model - to be used in estimating the overall non-point source pollutant load that is generated in the study area and in evaluating the effectiveness of various control strategies or pollution abatement techniques in reducing the above non-point source pollutant load.

3. INSTREAM TRANSPORT AND CONDITIONS

a. identify the impacts on receiving water quality that can result from the input pollutant loads identified in the Pollution Generation component;

b. complete the preliminary assessment begun in the Pollutant Generation phase of the relative importance of urban runoff pollution in relation to other sources;

c. determine the input pollutant load into Upper Mystic Lake that is transported by the Aberjona River;

d. identify water quality problems in the Aberjona River watershed in general and in the Aberjona River in particular;

e. provide an analytical tool that may be used to evaluate the effects of various pollution abatement measures or techniques.

4. INLAKE CONDITIONS

a. to increase understanding of quality conditions in the Upper Mystic Lake which impact water uses of concern, such as swimming, fishing, and aesthetics;

b. to understand the chemical, physical, and biological processes that control these conditions;

c. to assess the contribution of urban runoff relative to other pollutant sources impacting the Lake; and

d. to predict lake quality response to various urban runoff control strategies.

5. CONTROL EVALUATION

a. to identify, in general, the alternative methods for dealing with the water quality, and storm water in particular, problems in the basin;

b. to establish the location, the quantity, and the quality of pollutants entering the basin under the different alternative control procedures. These loadings will be used to analyze the water quality effects of the alternatives;

c. to recommend feasible control alternatives for improving water quality in the Upper Mystic Lake.

Table 3-2: SUMMARY OF INSTREAM AND E.O.P. MONITORING

Date	Weather		Station Type		Parameters								Rainfall Range (inches)
	Dry	Wet	In-stream	E.O.P. (1)	D.O.	Metals	Nutrients	Other (2) Chemical	Solids	Other (3) Physical	Coliform Bacteria	Priority Pollutants	
2/2/81		x	x	x		x	x	x	x				.01-.60
2/11/81		x	x	x		x	x	x	x				.30-.50
4/2/81		x	x	x		x	x	x	x				.15-1.10
4/8/81	x		x				x	x	x				----
4/14/81		x	x	x	x	x	x	x	x	x	x		.15-.30
4/15/81	x		x				x	x	x	x			----
5/20/81	x		x	x		x	x	x	x	x	x		----
6/20/81		x	x	x		x	x	x	x				.20-1.45
6/22/81		x	x	x	x	x	x	x	x	x	x		.35-1.05
7/13/81		x	x	x	x	x	x	x	x	x	x		.05-.60
8/5/81	x	x	x	x	x	x	x	x	x	x	x		.35-1.55
8/12/81	x		x			x	x	x	x	x	x		----
8/19/81	x		x			x	x	x	x	x	x		----
8/25/81		x	x	x	x	x	x	x	x	x	x		.10-.30
9/2/81	x		x			x	x	x	x	x	x		----
9/17/81		x		x								x	.35-.43
9/23/81		x		x								x	.87-1.27

KEY

(1) End-of-Pipe
(2) Includes BODs, COD, Chlorides Oil and Grease, Sodium and Sulfate
(3) Includes pH and Temperature

Table 3-3: SUMMARY OF UPPER MYSTIC LAKE AND INLET MONITORING

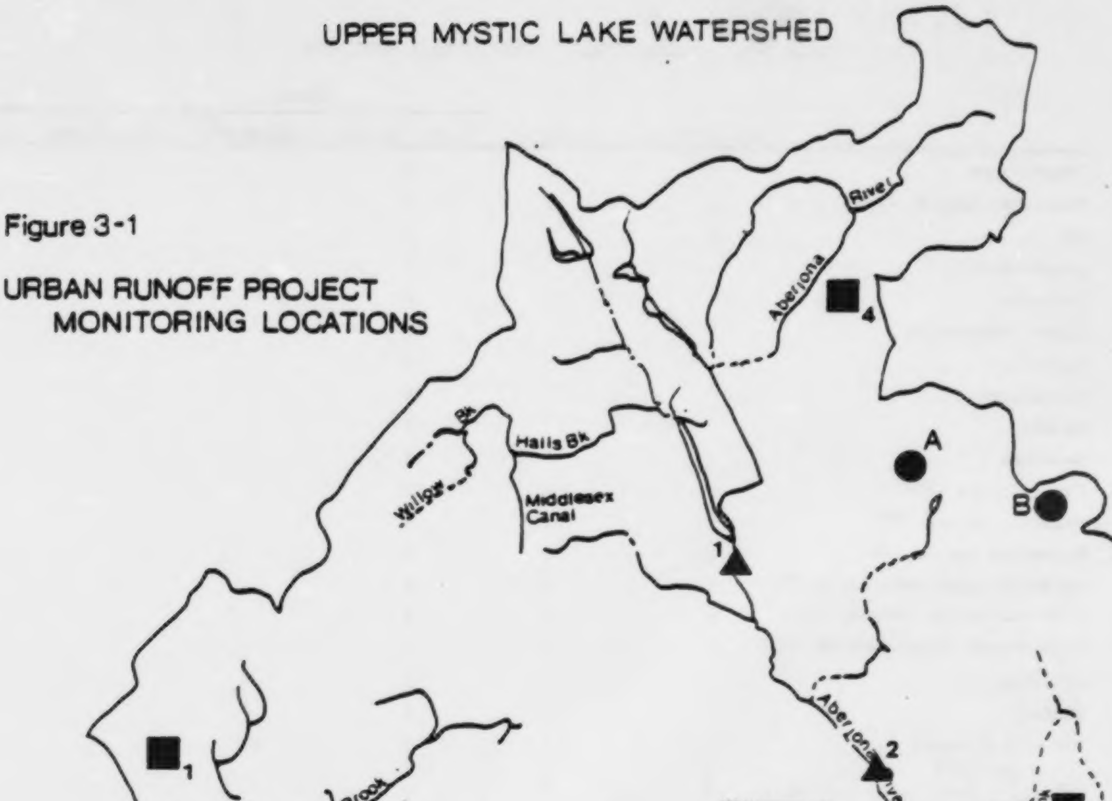
	12/9/80	4/15/81	5/20	6/5	6/15	6/16	6/22	6/23	6/25	7/13	7/28	8/5	8/6	8/7	8/8	8/12	8/19	8/20	8/25	8/26	8/27	8/31	9/2	9/16	9/17	9/19	9/23	9/28	10/14	11/12	5/21/82
INLAKE																															
Wet Weather Sampling								x					x	x	x				x	x	x			x	x	x	x				
Dry Weather Sampling	x								x	x	x							x										x	x	x	x
D.O., Temp. Profiles	x							x	x	x	x		x	x	x			x	x	x	x			x	x	x		x	x	x	x
Nutrient Series	x							x	x	x	x		x	x	x			x	x	x	x			x	x	x		x	x	x	x
Metal Series	x							x	x	x	x		x	x	x			x	x	x	x			x	x	x		x	x	x	x
Bacteria Samples		x							x	x	x		x	x	x			x	x	x	x			x	x	x		x	x	x	x
Algae Samples								x			x							x											x		
Bathymetric Survey				x																											
Dye/Circulation Study										x									x								x				
Fisheries Survey					x	x																									
Sediment Sampling													x	x																	
Macrophyte Survey										x			x	x																	
Benthic Macroinvertebrates										x			x	x																	
INLETS																															
Nutrient Series	x	x	x	x				x	x	x	x	x				x	x						x					x	x	x	
Metal Series	x		x					x	x	x	x	x				x	x						x					x	x	x	
Bacteria			x							x	x					x	x	x	x			x	x	x	x	x	x	x	x		

Table 3-4: WATER QUALITY CONSTITUENTS MONITORED

			Inlake		
	End-of-Pipe	Instream	Water Column	Sediments	Fish Flesh
Temperature	X	X	X		
Dissolved Oxygen (D.O.)	X	X	X		
pH	X	X	X		
Conductivity			X		
Salinity			X		
Light Penetration			X		
Turbidity			X		
Alkalinity			X		
Acidity			X		
Hardness			X		
Total Solids (TS)	X	X	X		
Volatile Solids (VS)		X	X		
Suspended Solids (SS)	X	X	X		
Volatile Suspended Solids (VSS)	X	X	X		
Chemical Oxygen Demand (COD)	X	X	X		
Biochemical Oxygen Demand (BOD)	X	X	X		
Chloride (Cl)		X	X		
Sulfate			X		
TKN - unfiltered	X	X	X	X	
- filtered	X	X	X		
Ammonia - unfiltered (NH_3+NH_4)	X	X	X		
- filtered	X	X	X		
Nitrate (NO_3)	X	X	X		
Nitrite (NO_2)	X	X	X		
Total Phosphorus (TP)					
- unfiltered	X	X	X	X	
- filtered	X	X	X		
Orthophosphate (PO_4)					
- unfiltered	X	X	X		
- filtered	X	X	X		
Aluminum (Al)	X	X	X	X	X
Arsenic (Ar)	X	X	X	X	X
Cadmium (Ca)	X	X	X	X	X
Chromium (Cr)	X	X	X	X	X
Copper (Cu)	X	X	X	X	X
Iron (Fe)	X	X	X	X	
Lead (Pb)	X	X	X	X	X
Magnesium (Mg)				X	
Manganese (Mn)	X	X	X	X	
Mercury (Hg)				X	X
Nickel (Ni)	X	X	X	X	X
Tin (Sn)	X	X	X	X	X
Zinc (Zn)	X	X	X	X	X
Total Coliform (TC)	X	X	X		
Fecal Coliform (FC)	X	X	X		
Priority Pollutants	X				

Figure 3-1

URBAN RUNOFF PROJECT MONITORING LOCATIONS


UPPER MYSTIC LAKE WATERSHED
Aberjona River
4
A
B
Halls Bk
Willow Bk
Middlesex Canal
1
Aberjona River
2
1
Little Brook
Cummings Brook
Wittemore Pond
3
Sweetwater Brook
3
Fowle Bk
Shaker Glen Brook
Horn Pond
5
4
Leonard Pool
Sucker Bk
Horn Pond Bk
Woburn Res
Winter Pd
Wedge Pd
2
6
Upper Mystic Lake
● End-of-Pipe
■ Rainfall
▲ In-Stream
1
0
1
miles

Mass. Department of Environmental Quality Engineering

the quantity and quality characteristics of runoff from relatively small homogeneous land use areas. The original monitoring strategy included four EOP sites, two of which were not sampled due to problems with equipment installation. The two sites sampled were Hemlock Road (EOP A) which drains a 50 acre residential area (85% residential, 15% open space) and Addison-Wesley (EOP B) which drains an 18 acre office park, both in Reading. The locations of these two sites are shown on Figure 3-1 and Figure 3-2.

Permanent equipment installations, consisting of automatic water quality samplers and sonic water level recorders, were established at both sites for the duration of the wet weather sampling program. Table 3-5 outlines the monitoring strategy for those sites. Flow rating curves were developed by fitting field measured velocities and channel characteristics to Mannings flow equation using a least square regression procedure; coefficients are summarized in Table 3-6. Rating Curves are shown in Appendix F.

The water quality samplers were triggered by a pre-established increase in water level and samples were collected for four hours. Samples were split to form three flow weighted composite samples at each location to economize on laboratory analysis. Ideally, the three composites were to represent the first 25%, the second 25% and the last 50% of the total runoff volume. The composites were analyzed for a number of parameters, as summarized in Tables 3-2 and 3-4.

The EOP data collected had three major limitations:

(1) baseflow samples were seldom collected since the consultant field crew was seldom on-site before events;

(2) grab samples for bacteria, dissolved oxygen and temperature were collected sporadically, again due to field crew scheduling; and

(3) the first composite sometimes contained a disproportionate portion of the runoff volume in order to have a large enough sample to analyze for all constituents.

Despite these limitations, the data collected was sufficient to characterize urban runoff from the two sites.

Storm drains discharging directly to Upper Mystic Lake were surveyed by DEQE, as shown in Figure 3-3, and a limited number of samples were collected at W5 and W7 which were identified as problem areas. Additionally, bacteria samples were collected by DEQE and the Winchester Town Engineering Office at four locations in the storm drain network which discharges to the Boat Club Inlet, to try to isolate a problem identified at that Inlet (see Figure 3-4).

In-stream

In-stream water quality was monitored at eight locations as shown in Figure 3-1 by wet weather consultants and DEQE urban runoff staff. Permanent installations were established by the field consultants at six sites:

TABLE 3-5: Permanent Installation Wet Weather Sampling Strategy

Site	Description	Equipment	Sampling	Composition (Chemistry)
EOP A	36" storm drain outfall draining a 50 acre residential area	flow: automatic liquid level sonic sensor quality: modified Manning automatic sampler: field measurement of bacteria, D.O. and temperature.	chemistry duration-4 hours frequency-10 min. bacteria/D.O./temp. 5 samples-3 on rising limb, 2 on recession limb.	baseline and 3 flow weighted composites based on total runoff volume - first 25%, second 25%, last 50%.
EOP B	manhole installation in 30" pipe draining an 18 acre office park	same as above	same as above	
IS 1	Aberjona River at Mishawum Rd. with an upstream drainage area of 4,157 acres which isolates the impacts of past industrial waste disposal practices in the upper basin	same as above	chemistry duration-24 hours frequency-15 min. bacteria/D.O./temp. 5 samples-3 on rising limb, 2 on recession limb.	baseline and 4 flow weighted composites based on total river volume-first, second, third and fourth 25%.
IS 2	Aberjona River at Hill Street, approximately 2½ miles downstream of IS 1 with the intervening reach characterized by a shallow swampy area.			
IS 3	Sweetwater Brook at Maple Street which drains 1,490 acres and is the most heavily urbanized sub-basin within the study area.			
IS 4	Aberjona River at Washington Street 2½ miles above IS 6.			
IS 5	Outlet of Horn Pond approximately 1.1 miles above the confluence of Horn Pond Brook (6272 acre sub-basin) and the Aberjona.			
IS 6	Aberjona River at the USGS gauge located approximately ½ mile above the Upper Mystic Lake.	quality: same as above flow: 15 minute stage readings are recorded at the USGS gauge.		

FIGURE 3-2: E.O.P. DRAINAGE AREAS

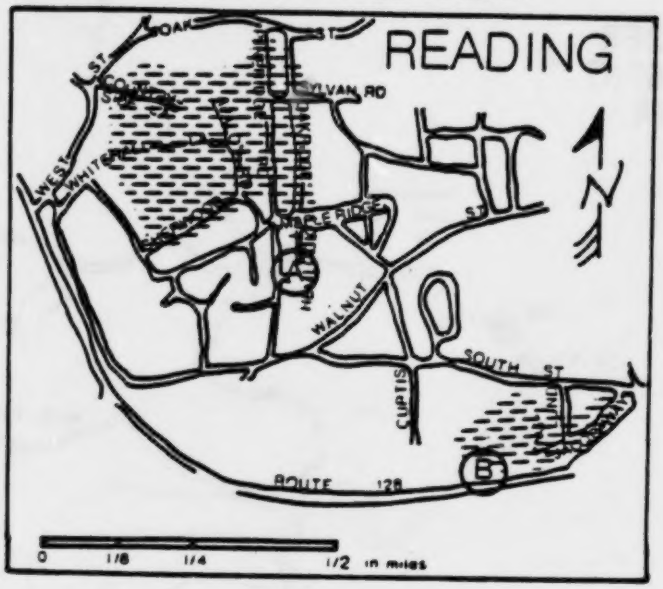

READING
OAK
ST
ST
YLVAN RD
WEST
WHITEH
MAPLE RIDGE
ST
WALNUT
SOUTH ST
CURTIS
B
ROUTE 128
N
0
1/8
1/4
1/2 in miles

Table 3-6: FLOW RATING CURVE SUMMARY

Station	Roughness Coefficient	Best Fit Slope
EOP A	.015	.007780
EOP B	.015	.037328
IS1	.015	.001434
IS2	.025	.001612
IS3	.017	.000748
IS4	.025	.000123
IS5	--	--
IS6	--	--

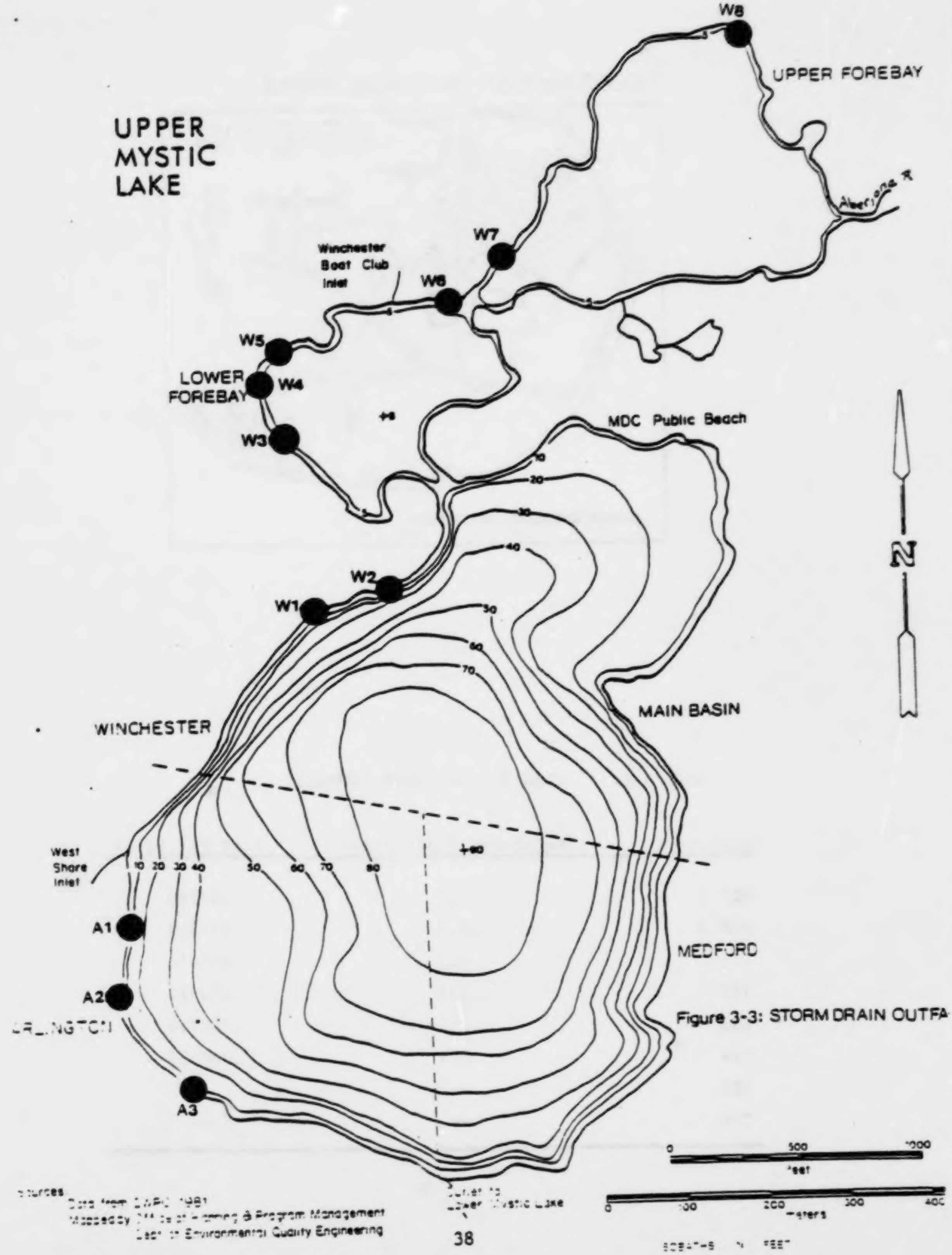

UPPER MYSTIC LAKE
W8
UPPER FOREBAY
Aberjona R
W7
Winchester Boat Club Inlet
W6
W5
LOWER FOREBAY
W4
W3
MDC Public Beach
W2
W1
10
20
30
40
50
60
70
80
+90
MAIN BASIN
WINCHESTER
West Shore Inlet
A1
A2
ARLINGTON
MEDFORD
A3
N
0
500
1000
feet
0
100
200
300
400
meters
Outlet to Lower Mystic Lake
ISOBATHS IN FEET

Figure 3-3: STORM DRAIN OUTFA

Sources:
Data from DWPC 1981
Mapped by Office of Planning & Program Management
Dept. of Environmental Quality Engineering

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best available copy.

KEY TO FIGURE 3-3

Station	Location
	Arlington:
A1	Mystic Street
A2	Neil Way
A3	Parker Road
	Winchester:
W1	Cambridge Street
W2	Robinson Park
W3	Cambridge Street
W4	Cambridge Street
W5	Cambridge Street
W6	Edgewater Place
W7	Niles Lane
W8	Lakeview Road

Sources: Winchester Engineering Office
Arlington Department of Public Works
Field Verified by DEQE Staff

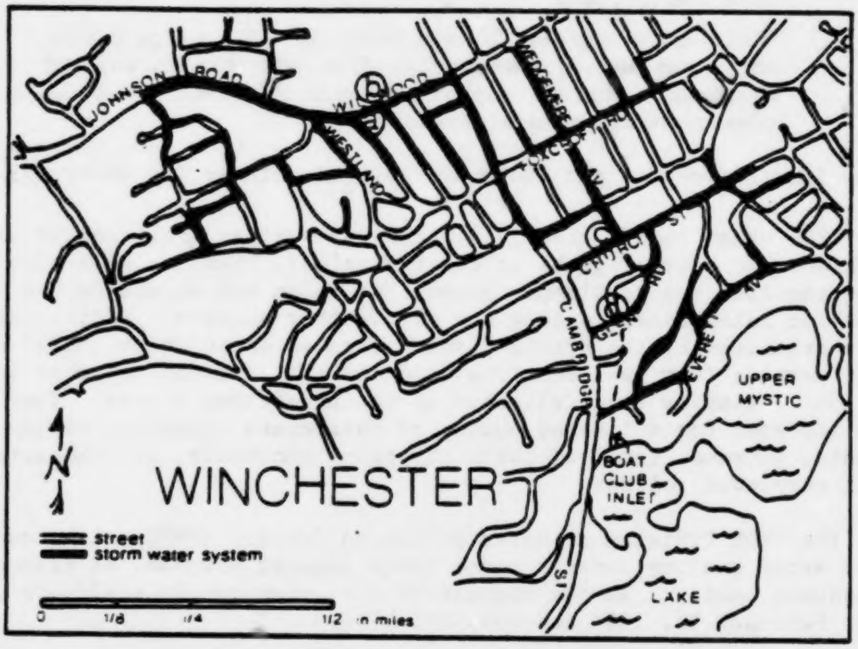

JOHNSON ROAD
WILDWOOD
WESTLAND
WEDGEMERE
FOXCROFT RD
AV
CHURCH ST
GLEN RD
CAMBRIDGE ST
EVERETT AV
UPPER MYSTIC
BOAT CLUB INLET
LAKE
WINCHESTER
N
street
storm water system
0
1/8
1/4
1/2 in miles

Figure 3-4: BOAT CLUB INLET STORMWATER DRAINAGE AND SAMPLING LOCATIONS

IS1 Aberjona River at Mishawum Road,
IS2 Aberjona River at Mill Street,
IS3 Sweetwater Brook at Maple Street,
IS4 Aberjona River at Washington Street,
IS5 Horn Pond Outlet, and
IS6 Aberjona River at the USGS gauge.

The additional two stations were on the West Shore and Boat Club Inlets. Tables 3-2 and 3-4 summarize the type of data collected at these eight sites.

As with the EOP sites, permanent installations consisted of automatic water quality samplers and sonic water level recorders. The latter was not installed at IS6, however, since continuous stage levels were recorded at the USGS gauge at that site. Rating curves, relating water level to flow, were developed from field measurements. Rating curve coefficients are summarized in Table 3-6. Samples were collected for twenty-four hours after runoff began and were composited into four flow weighted samples. The data collected generally had the same limitations as discussed for the EOP sites. There were, however, two additional site-specific problems:

(1) Data collected at the Horn Pond Outlet (IS5) were extremely limited due to outflow regulation by the City of Woburn; a flow rating curve could not be developed and quality samples were only collected for four events; and

(2) field crews did not always read the USGS gauge during the event and, consequently, flow information was not available when the composites were made; in those cases time composites were developed.

These limitations did not, however, severely hinder the water quality analysis.

DEQE urban runoff staff collected dry weather grab samples at all eight sites and wet weather grabs at the two inlets. Samples were also collected along the Aberjona at Olympia Avenue and Salem Street and on the unnamed tributary at Salem Street during the dry weather surveys. Additionally, volunteers organized by the Mystic River Watershed Association (MRWA) collected water samples from two locations (IS6 and IS1) between November 1980 and August 1981. Samples were collected up to three times a week. The MRWA samples were analyzed for a limited number of parameters (chemical oxygen demand, ammonia, nitrate, total kjeldahl nitrogen, phosphate, oil and grease, and total suspended solids).

The DEQE Division of Water Pollution Control (DWPC) also conducted three river water quality surveys under their ongoing program, as discussed in a subsequent section, at the request of the urban runoff staff (October 29, 1980, 1980, February 26, 1981 and July 29, 1981).

Upper Mystic Lake

Bathymetric Survey. A bathymetric survey was conducted by the DEQE urban runoff staff and the Division of Water Pollution Control (DWPC). Using a sonar depth sounder, the bottom contours of the lake were recorded.

Sampling Stations. Seven separate lake stations were established on the Upper Mystic Lake as shown on Figure 3-5:

Station A: Center of upper forebay,
Station B: Center of lower forebay,
Station 1: Neck between upper and lower forebay,
Station 2: Neck between lower forebay and main basin,
Station 3: Sandy Beach (MDC public beach),
Station 4: Deep center hole in main basin, and
Station 5: Outlet to Lower Mystic Lake (samples taken upstream of spillway).

In-lake Water Quality Monitoring. In-lake monitoring was conducted by DEQE urban runoff staff during dry and wet weather conditions. Dry weather sampling was conducted monthly from June 1981 to November 1981 in conjunction with the Metropolitan District Commission (MDC) and the DEQE Division of Water Pollution Control (DWPC). Additional samples were taken in December 1980 and May 1982.

Wet weather sampling was conducted by the sampling consultants, Environmental Design and Planning (EDP). Wet weather monitoring involved three consecutive in-lake sampling runs 24, 48 and 72 or 96 hours after the beginning of a storm event. Three individual storms were monitored, two in August 1981 and one in September 1981.

Temperature and dissolved oxygen profiles and transparency measurements were made in the center of each of the three basins at Station A, B and 4. Transparency measurements were made with a standard 20 cm. secchi disk. Nutrient and metal samples were collected in-lake at Stations 1, 2, 4 and 5. A chemical profile was done in the deep basin (Station 4) which consisted of three samples based on the daily temperature profile: epilimnion (4a), mid-metalimnion (4b), and hypolimnion (4c). Dry weather samples at 4c were collected ½ meter above the sediments. Unfortunately, wet weather samples at 4c were taken at mid-hypolimnion, so they cannot be directly compared to those collected during dry weather. Samples collected at Stations 1, 2 and 5 were taken at mid-depth of the channel. Bacteria samples were collected in-lake at Stations 1, 2, 3, 4 and 5 under dry and wet weather conditions. Bacteria samples collected during the circulation studies were taken from a pre-established grid.

Sediment Sampling. Four grab surface sediment samples were collected by EDP using a Peterson dredge (size: 1 ft^2). One grab sample was taken in the center of each of the three basins and one at the mouth of the Aberjona River. The depth of the sediments at each site was also determined.

Fisheries Survey. A fisheries survey was conducted by DEQE urban runoff staff and the Division of Fisheries and Wildlife during June 1981. Two techniques were used, gill nets and pole electro-shocking, to determine population composition and density. Gill nets were set up, in the upper forebay and in the main basin, each stretching perpendicular to the shoreline. Pole shocking was done along most of the littoral zone of the upper forebay and for a timed distance in the main basin (see Figure 3-6). Fish flesh samples were collected from each species and analyzed for heavy metals to determine the suitability of fish for human consumption.

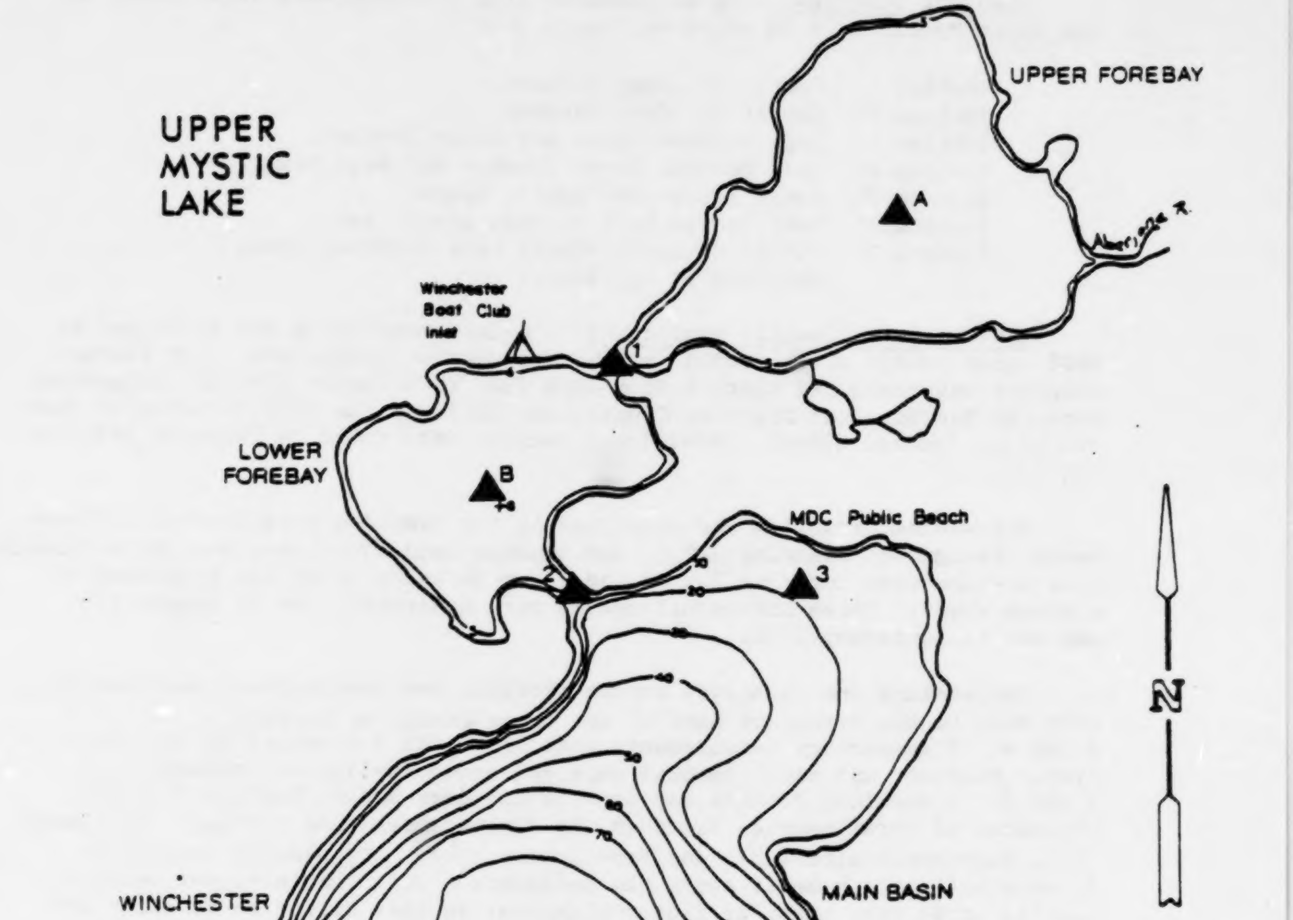
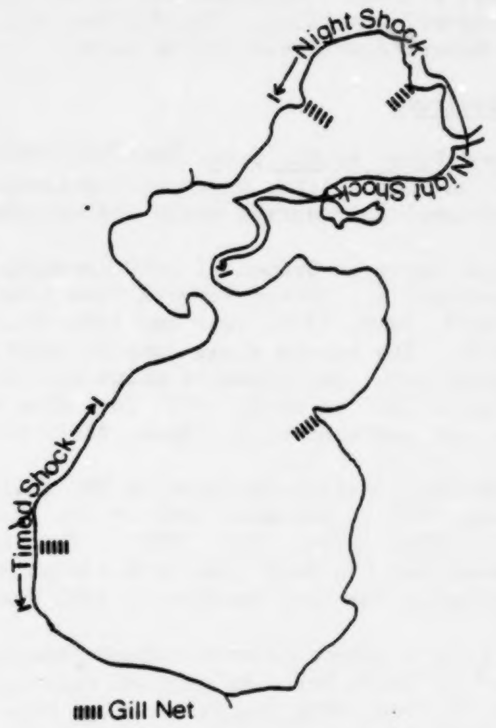

UPPER MYSTIC LAKE
UPPER FOREBAY
A
Aberjona R.
Winchester Boat Club Inlet
1
LOWER FOREBAY
B
MDC Public Beach
2
3
10
20
30
40
50
60
70
80
MAIN BASIN
WINCHESTER
West Shore Inlet
4
90
MEDFORD
ARLINGTON
Outlet to Lower Mystic Lake
N
0
500
1000
feet
0
100
200
300
400
meters
ISOBATHS IN FEET

Figure 3-5: URBAN RUNOFF PROJECT MONITORING LOCATIONS

Sources:
Data from DWPC 1981
Mapped by Office of Planning & Program Management
Dept of Environmental Quality Engineering

Figure 3-6 : 1981 SUMMER FISHERIES SURVEY



Aquatic Vegetation. Vegetation surveys were conducted by DEQE urban runoff staff and DWPC in the spring, summer and fall. Aquatic vegetation in the Lake was located and mapped with respect to population, composition and distribution. Surveys were conducted by boat and foot.

Benthic Macroinvertebrates. Bottom samples were collected in the center of each basin and at the mouth of the Aberjona River using a Peterson dredge (size: 1 ft.^{2}). Samples were sieved (#30 standard sieve) and invertebrates were preserved.

Phytoplankton. Phytoplankton samples were collected by DEQE urban runoff staff and DWPC using a composite core as described by DWPC (Mass. DEQE, 1975).

Circulation Study. A series of three circulation studies based on a range of flow conditions (typical low summer to high spring flows) were conducted on Upper Mystic Lake by the sampling consultants. Rhodamine B dye was pumped into the Lake at 2 locations: below the Aberjona River bridge, and into the channel between the lower forebay and main basin. Dye was traced over time on a pre-established grid system (up to 24 hours) using visual observations and measured fluorimetric concentrations. In the main basin, fluorimetric samples were taken from the lake surface to a depth of 10 feet.

Additional Source Sampling

DEQE urban runoff staff also collected samples in the drainage ditches off of Eames Street in Wilmington, as shown in Figure 3-7. This area is considered a "special problem", as discussed in Chapter 5.0, due to past and present waste disposal practices. The ditches join Halls Brook, a tributary of the Aberjona River, downstream of the site.

Other Sampling Programs

In-stream and Upper Mystic Lake. The DEQE Division of Water Pollution Control (DWPC) and the Metropolitan District Commission (MDC) both have established long-term sampling programs which include the Mystic River Basin.

The Technical Services Branch of DWPC conducts stream and lake surveys throughout Massachusetts. Stream surveys have been conducted in the Mystic Basin in 1967, 1973, 1978, 1979, 1980 and 1981 (Mass. WRC, 1974a,b; Mass. DEQE 1981c, 1982d). The stream sites sampled during the most recent surveys are shown in Figure 3-8. An intensive study on the Upper Mystic Lake was conducted from April 1974 to April 1975, including monthly chemical surveys, biological data, and sediment cores (Mass. DEQE, 1975).

The Environmental Quality Division of MDC collected monthly stream samples from September 1972 to December 1980 at the stations shown on Figure 3-9 (Mass. MDC, 1977, 1978, 1979a, 1980, 1981). They also collected monthly lake data at Sandy Beach and the deep hole site except when there was ice cover. The sampling frequency has been reduced in 1982 due to budget limitations.

There have been a number of more limited monitoring programs on the Aberjona River listed in Table 3-7. As part of this project, CDM (1980b) summarized the results of these data sources, noting that it comprises an extremely fragmented data base due to changes in sampling locations and constituents analyzed.

Additionally, samples were collected on the Upper Mystic Lake in March, May and June of 1970 and January and February of 1971 by Jason M. Cortell (1970, 1971) for the Metropolitan District Commission.

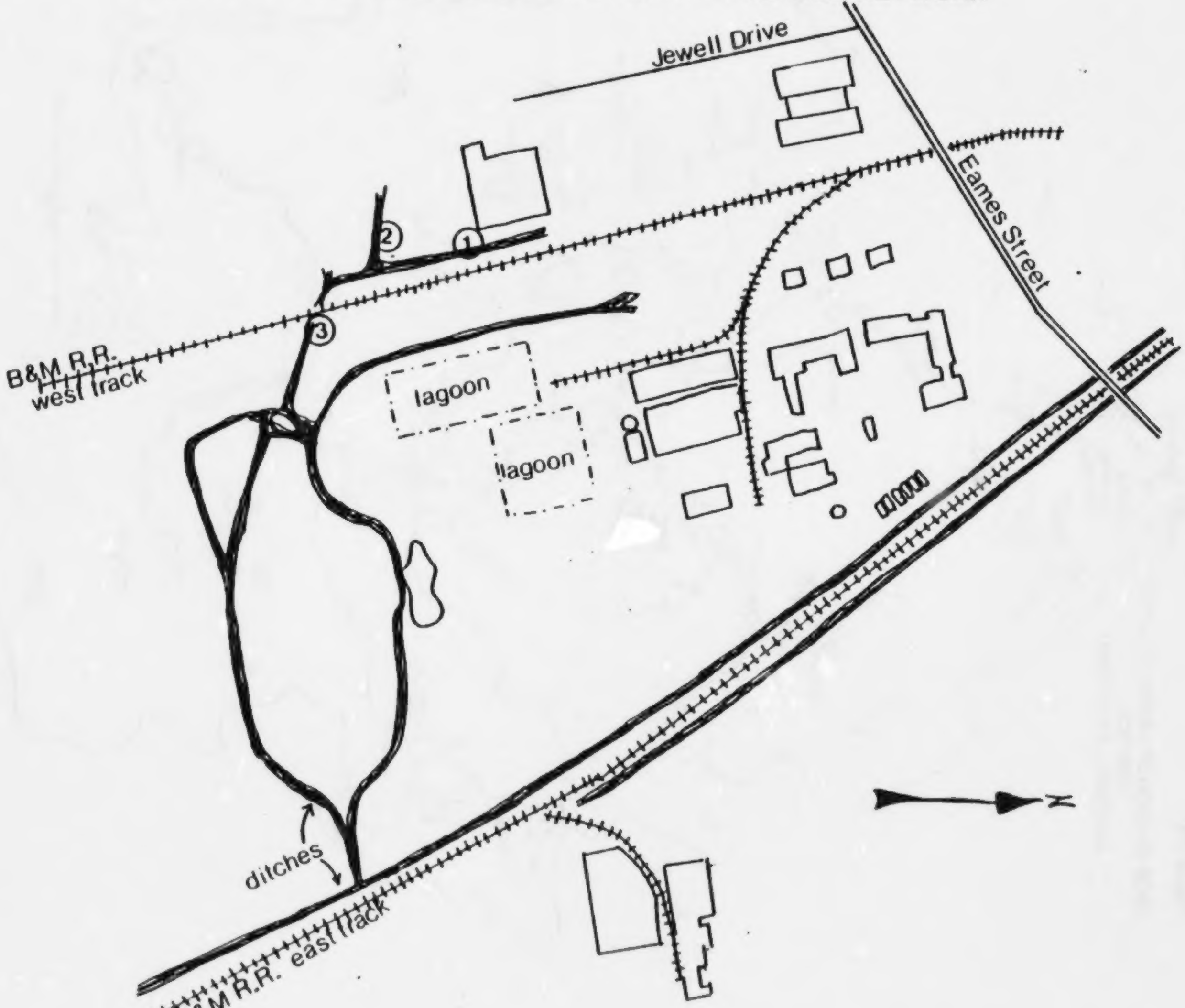
As part of a screening program for priority pollutants, DEQE and EPA sampled for volatile organics at the stream and lake locations shown in Figure 3-10 in July of 1980.

Urban Runoff and Other Sources. The DWPC collected a limited number of stormwater samples in the Mystic River Basin for the Metropolitan Area Planning Council in the fall of 1977 (Mass. DEQE, 1977). That program included one stormwater outfall to the Upper Mystic Lake: station A2 on Figure 3-3.

The DWPC surveyed point source discharges in 1975, collecting samples at four locations in the Watershed (Mass. DEQE, 1975). DWPC also collects samples in the drainage ditches south of Eames Street in Wilmington as part of their long-term sampling program discussed above (see Figure 3-8). Priority pollutant samples were also collected at two sites along the drainage ditches as part of the EPA/DEQE sampling program (see Figure 3-10).

The DEQE Divisions of Hazardous Waste and Water Pollution Control, and the EPA have collected a variety of data from the industrial areas in North and East Woburn in an ongoing effort. Included are groundwater, soil, leachate, and waste samples.

Figure 3-7: WILMINGTON INDUSTRIAL AREA - DRAINAGE NETWORK


Jewell Drive
Eames Street
B&M R.R. west track
lagoon
lagoon
①
②
③
ditches
B&M R.R. east track
N

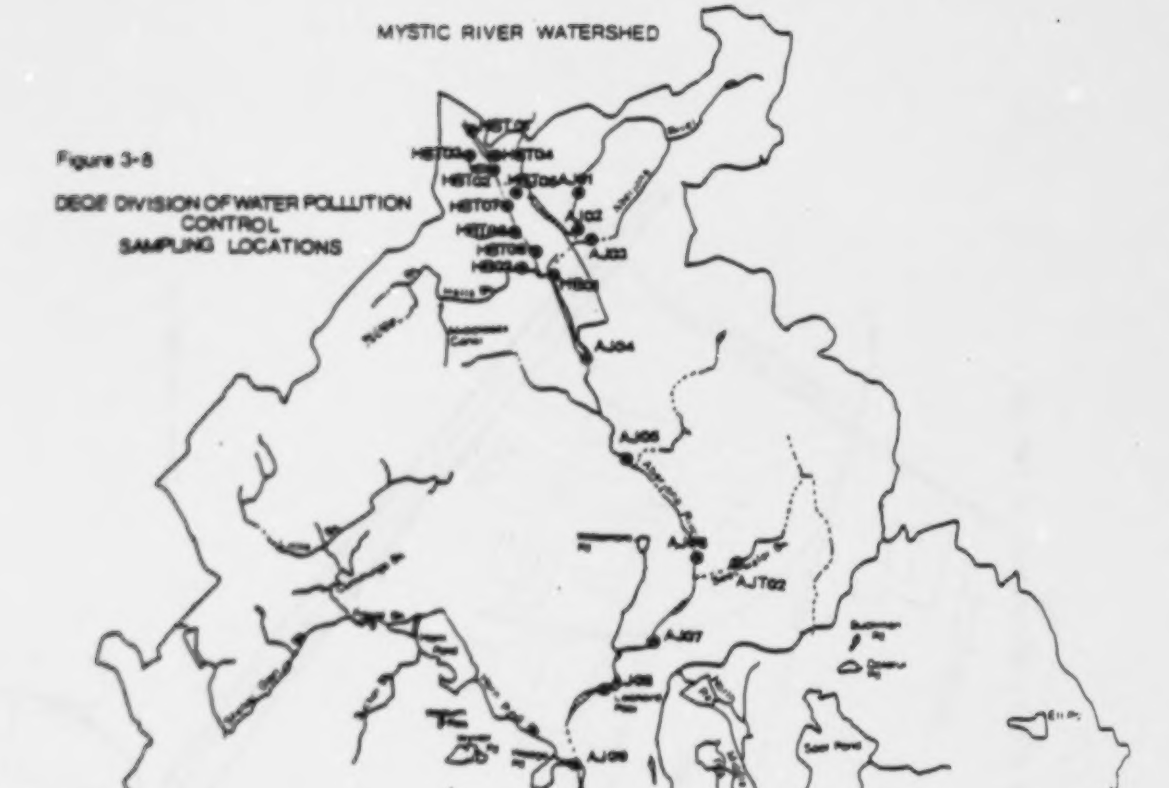

MYSTIC RIVER WATERSHED
HST02
HST07
AJ02
AJ03
AJ04
AJ05
AJT02
AJ07
AJ08
AJ09
AJ10
MY12
MY11
MY13
MY15
MY16A
MY16
MY17 A
Mystic River
miles

Figure 3-8

DEQE DIVISION OF WATER POLLUTION CONTROL SAMPLING LOCATIONS

Mass. Department of Environmental Quality Engineering

KEY TO FIGURE 3-8

STATION	LOCATION	RIVER MILE
AJ01	Aberjona River (North Branch) downstream of its confluence with an unnamed tributary off gravel road extension of Commerce Road, Woburn	15.8
AJ02	Aberjona River (North Branch) at end of Commerce Road, Woburn	15.7
AJ03	Aberjona River (South Branch) upstream of its confluence with North Branch, east of Commerce Road, Woburn	15.6,0.1
AJ04	Aberjona River, south of Mishawum Road, off parking lot of 99 Restaurant, Woburn	14.4
AJ05	Aberjona River at Salem Street bridge, Woburn	13.2
AJ06	Aberjona River at Mount vale Avenue bridge, Woburn	12.0
AJ07	Aberjona River at Washington Street bridge, Winchester	11.2
AJ08	Aberjona River at Swanton Street bridge, Winchester	10.2
AJ09	Aberjona River, downstream of Wedge Pond at Main Street bridge, Woburn	9.8,0.1
AJ10	Aberjona River at USGS gauging station, on east bank of river, off Grove Street, Winchester	9.0
AJ11	Aberjona River, directly upstream of Upper Mystic Lake, at Mystic Valley Parkway bridge, Winchester	8.6
MY10	Outlet of Upper Mystic Lake, at eastern part of dam separating Upper and Lower Mystic Lake off Mystic Valley Parkway, Medford	7.4
MY11	Mystic River, directly downstream from Lower Mystic Lake, at Mystic Valley Parkway bridge, Medford/Arlington	6.6
MY12	Mill Brook, upstream of its confluence with Lower Mystic Lake, at Mystic Valley Parkway bridge, Arlington	6.8,0.1
MY13	Alewife Brook at Mystic valley Parkway bridge, Arlington/ Somerville	5.8,0.1
MY14	Alewife Brook at Massachusetts Avenue, Arlington/Somerville	5.8,0.1
MY15	Mystic River at Route 38 bridge, Medford	5.8,1.0
MT16A	Tributary 20-25 meters downstream of MY15, on northern bank of river at Route 16, Medford	5.0,0.1
MY17A	Malden River at Medford Street bridge, Malden	2.2,1.4
MY18	Mystic River on northern bank directly upstream from Amelia Earhart Dam, off Scenic Mystic Road, Everett	2.0

STATION	LOCATION	RIVER MILE
HB01	Halls Brook at Boston & Maine R.R. bridge, upstream of New Mishawum Lake off New Boston Road, Woburn	14.7,0.7
HB02	Halls Brook upstream of New Boston Road, Woburn	14.7,0.9
AJT01	Unnamed tributary to Aberjona River off Salem Street, double culvert in dirt drive	13.2,0.2
AJT02	Sweetwater Brook at Maple Street bridge, Stoneham	11.7,0.5
AJT03	Pond Brook, downstream of Horn Pond at Lake Avenue bridge, Woburn	9.8,1.2
AJT04	Shaker Glen Brook at Lexington Street bridge, Woburn	9.8,2.6
AJT05	Cummings Brook at Lexington Street bridge, Woburn	9.8,2.7
HBT01	Western drainage ditch along Boston and Maine R.R., south of Eames Road in Wilmington (flow entering Stepan Chemical Company site)	
HBT02	Unnamed stream, upstream of its confluence with western drainage ditch alongside of Boston and Maine R.R. approximately ¼ mile south of station HBT01 along railroad, south of Eames Road in Wilmington	
HBT03	Unnamed stream where it passes under Boston and Maine R.R. spur west (upstream) of station HBT02, south of Eames Road, Wilmington	
HBT04	Pipe under Boston and Maine R.R., across from station HBT02, Wilmington	
HBT05	Western drainage ditch alongside of Boston and Maine R.R., south of New England Resin & Pigments Company industrial park, Woburn	
HBT06	Unnamed tributary upstream of its confluence with western drainage ditch along Boston and Maine R.R., north of Merrimack Street, off New Boston Road, Woburn	
HBT07	Unnamed tributary to western drainage ditch along Boston and Maine R.R., upstream of its confluence, approximately five meters west of HBT05, Woburn	
HBT08	Western drainage ditch along Boston and Maine R.R., upstream upstream of New Mishawum Lake, off Boston Road, Woburn	

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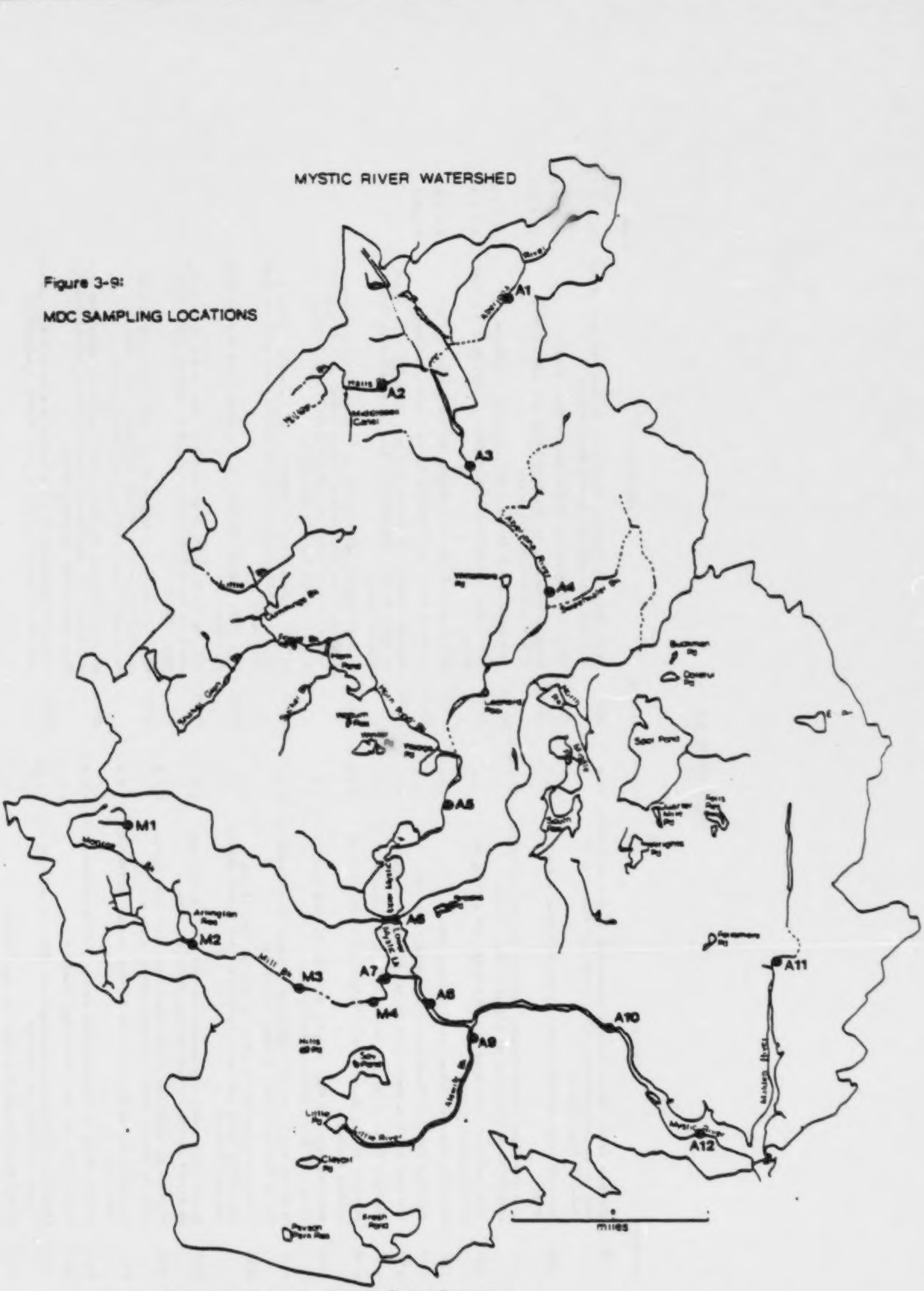
best available copy.



MYSTIC RIVER WATERSHED
A1
A2
A3
A4
A5
A6
A7
A8
A9
A10
A11
A12
M1
M2
M3
M4
Middlesex Canal
Aberjona River
Horn Pond
Spot Pond
Arlington Res.
Mill Br.
Alewife Br.
Little River
Little Pd
Clay Pit Pd
Spy Pond
Hills Pd
Fresh Pond
Payson Park Res
Mystic River
Malden River
miles

Figure 3-9:

MDC SAMPLING LOCATIONS

Mass. Department of Environmental Quality Engineering

KEY TO FIGURE 3-9

Station		River Mile
A1	Aberjona River Route 129, Reading	17.5
A2	Halls Brook New Boston Street, Woburn	16.2
A3	Aberjona River Olympia Street, Woburn	14.8
A4	Aberjona River Montvale Avenue, Woburn	12.7
A5	Aberjona River USGS Gauging Station, Winchester	9.7
A6	Mystic Lakes - Dam Overflow Winchester	8.1
A7	Mill Brook At Mystic Valley Parkway, Arlington	7.4
A8	Mystic River High Street, Medford (Rt. 60)	7.2
A9	Alewife Brook At Mystic Valley Parkway, Somerville	6.5
A10	Mystic River Winthrop Street, Medford	6.0
A11	Malden River Winthrop Street, Medford	2.7
A12	Mystic River Wellington Bridge, Somerville-Medford	2.2
M1	Massachusetts Avenue, Lexington	4.0
M2	Arlington Reservoir Outlet	2.9
M3	Brattle Street, Arlington	1.6
M4	Mystic Street, Arlington	0.5

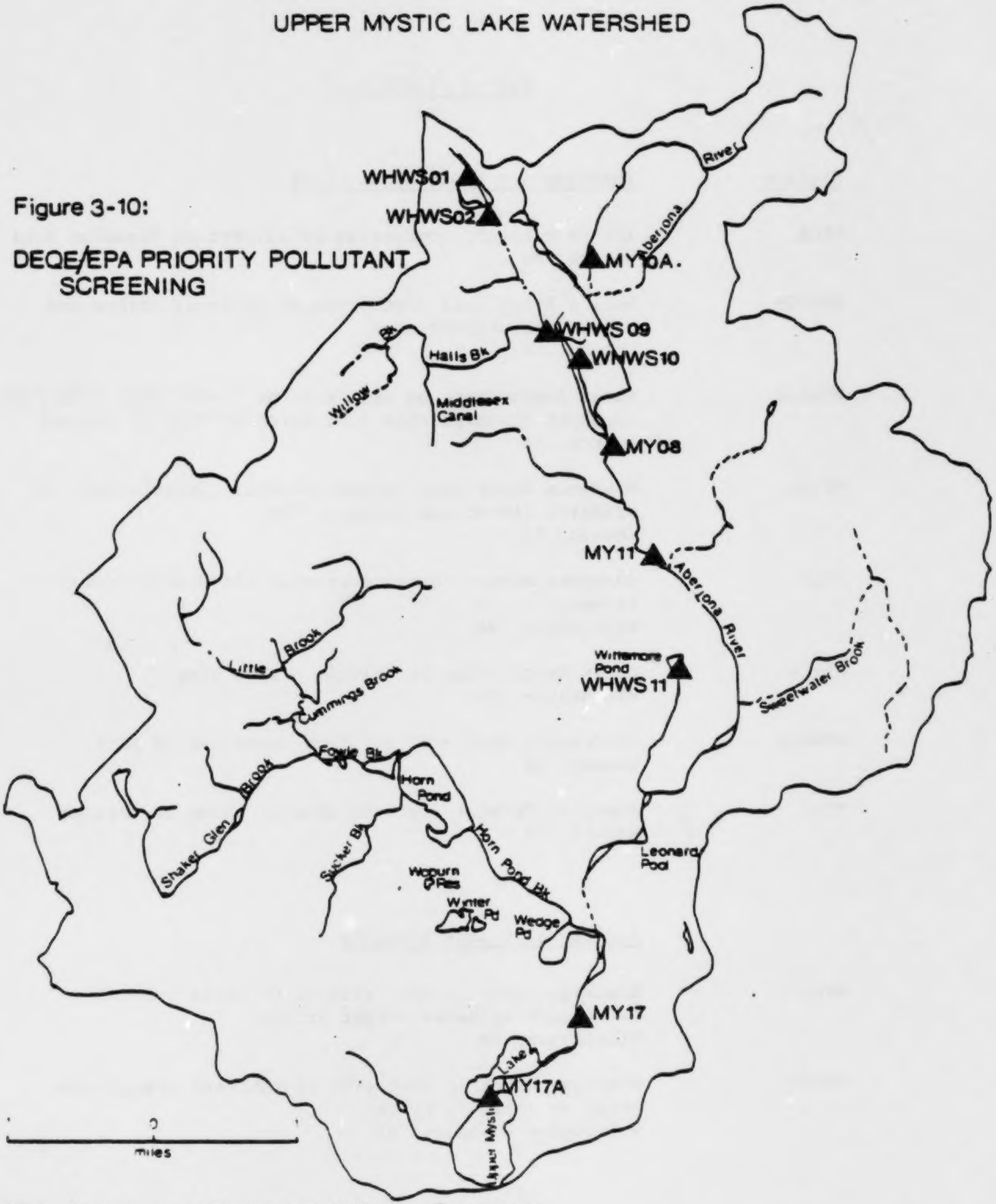
Table 3-7: ADDITIONAL ABERJONA RIVER MONITORING

Sampling Dates	Data Sources
7-13-67 7-19-67 7-27-67 8-02-67 8-08-67 8-14-67	Camp Dresser & McKee, Inc. (1967) for the Aberjona River Commission
6-16-71 7-07-71 7-28-71	Tufts University (Defeo, 1971) for the Aberjona River Commission
6-06-73	U.S. Geological Survey (1973)
3-21-77 5-02-77 7-05-77 9-06-77	Metropolitan Area Planning Council (1977a)
5-03-79 5-24-79 5-25-79 7-09-79 8-13-79 9-06-79	Interdisciplinary Environmental Planning, Inc. for Camp Dresser and McKee, Inc. (1981a)

UPPER MYSTIC LAKE WATERSHED

Figure 3-10:

DEQE/EPA PRIORITY POLLUTANT SCREENING


WHWS01
WHWS02
River
Aberjona
MY10A.
WHWS 09
WHWS10
Halls Bk
Willow Bk
Middlesex Canal
MY08
MY11
Aberjona River
Wittemore Pond
WHWS 11
Scelwater Brook
Little Brook
Cummings Brook
Fowle Bk
Horn Pond
Horn Pond Bk
Shaker Glen Brook
Sucker Bk
Woburn Res
Winter Pd
Wedge Pd
Leonard Pool
MY17
MY17A
Lake
Upper Mystic
0
miles

Mass. Department of Environmental Quality Engineering

KEY TO FIGURE 3-10

Station	Instream and Upper Mystic Lake
MY08	Aberjona River, downstream of culvert on Mishawum Road Woburn, MA
MHWS09	Hall's Brook just downstream of railroad bridge and before impoundment area Woburn, MA
WHWS10	Water impoundment on Hall's Brook - east bank - 50 feet south of drainage pipe just north of Digital Company Woburn, MA
MY10A	Aberjona River just before culvert. Intersection of Atlantic Street and Commerce Way Woburn, MA
MY17	Aberjona River - gauging station off Mystic Valley Parkway Winchester, MA
MY17A	Upper Mystic Lake at Narrows - east side Winchester, MA
WHWS11	Whittemore Pond - 50 ft. from south end of pond Woburn, MA
MY11	Aberjona River - upstream side of Salem St. bridge Woburn, MA
	Additional Source Sampling
WHWS01	Drainage ditch on west side of railroad tracks. South side of Eames Street bridge. Wilmington, MA
WHWS02	Drainage ditch on west side of railroad tracks just prior to entering culvert Wilmington - Woburn, MA

3.3 DATA ANALYSIS

The analytical methods used in each of the four study elements described previously are summarized in this section. More detailed descriptions of these methods can be found in the consultant reports listed in Chapter 1.0 and in the other references cited.

Precipitation

Long-term Characteristics. A description of the long-term precipitation characteristics was developed by the data analysis consultants, Camp Dresser and McKee, using historic records from the National Weather Service Station at Logan Airport and the MDC Station at Spot Pond (CDM, 1980a).

The Rainfall Analysis Model (RAM) developed by CDM was used to define the following (using hourly data):

- time interval between storms (hours),
- storm duration (hours),
- storm depth (inches), and
- average storm intensity (inches/hour).

Each of these parameters was expressed in terms of its monthly mean, standard deviation and skewness. Independent storm events were defined as two periods of precipitation separated by more than two rainless hours.

Monitored Storm Records. The data collected at the four hourly stations established in the Watershed was used to develop the parameters listed above for each storm event monitored. The daily data recorded by MRWA volunteers was used to analyze the distribution of rainfall across the Watershed. An average depth of precipitation for each event was calculated using the Theissan Weights Method as described by CDM (1982).

Pollutant Generation

The data analysis consultants, Camp Dresser and McKee, simulated the long-term quantity and quality characteristics of urban runoff in the Upper Mystic Lake Watershed using the Storage Treatment Overflow Runoff Model (STORM). The application of that model is described in detail by CDM (1982) in their final report and will only be briefly summarized in this section.

The analysis of pollutant generation was done at two distinct levels of detail. The end-of-pipe data collected at the two homogeneous land use types and instream data were evaluated to determine specific characteristics and model coefficients for specific land uses. At the second and broader level of detail, runoff characteristics were simulated for seven sub-basins within the Upper Mystic Lake Watershed, with mixed use as described below.

Watershed Segmentation and Land Use. Segmentation of the Upper Mystic Lake Watershed was based on hydrologic boundaries, location of in-stream sampling stations, and location of major inflows. In total, seven sub-basins

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were used in model calibration:

(1) Mishawum - 4,021 acres,
(2) Unnamed Tributaries - 1,800 acres,
(3) Sweetwater - 1,450 acres,
(4) Direct River - 1,650 acres,
(5) Horn Pond - 1,145 acres,
(6) Muraco - 620 acres, and
(7) Highland - 620 acres.

Three other sub-basins which drain directly to the Upper Mystic Lake were also delineated, but were not included in the calibration:

(8) Boat Club Inlet - 495 acres,
(9) West Shore Inlet - 480 acres, and
(10) Direct Lake Drainage - 540 acres.

These sub-basins are delineated in Figure 3-11. As shown there, the Horn Pond sub-basin with a total drainage of 6,518 acres was further divided for calibration (dashed line). Drainage from the upper area is regulated by the City of Woburn at the Horn Pond outlet and flow from the pond occurs infrequently. Consequently, since limited data were collected during the sampling program, all drainage upstream of the outlet was disregarded for the calibration.

The land use characteristics of the eleven sub-basins are presented in Tables 3-10 and 3-11. Initially, the Watershed was divided into five categories: low-density residential, medium-density residential, office park/industrial, commercial, and other. In order to eliminate the ambiguous "other" category and better correlate land use with field observations, existing land uses were aggregated into three groups: residential, commercial/industrial and open space.

STORM Description. STORM uses three basic algorithms to simulate the quantity and quality of runoff. These will be presented here and the procedures used for calibration and derivation of the coefficients discussed. Again, a more detailed description is provided by CDM (1982).

STORM simulates runoff quantity independent of quality. Runoff quantity is computed using a variation of the Rational Formula:

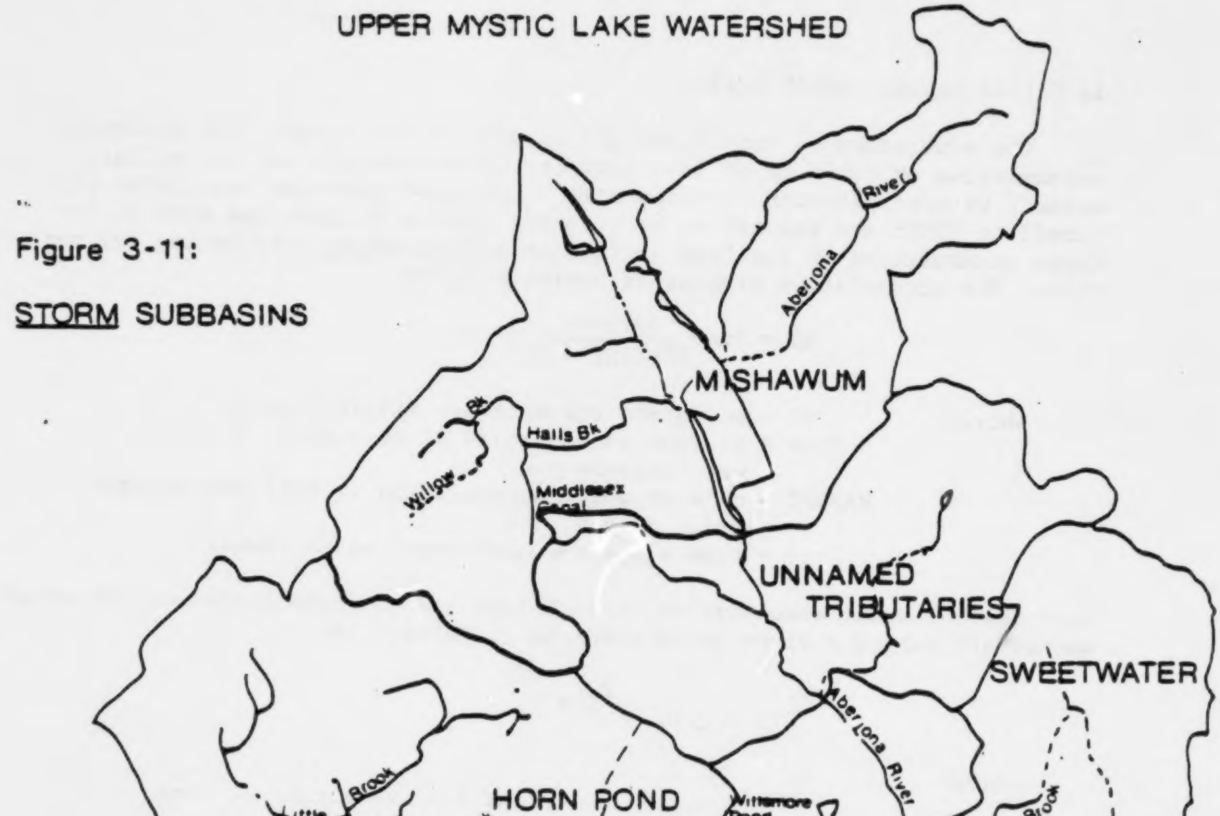
$$Q = C(I-D)A$$

where:
Q = runoff flow rates (cfs),
C = runoff coefficient (fraction related to land use),
I = rainfall intensity (inches/hour),
D = depression storage (inches), and
A = drainage area (acres).

Depression storage represents the ponding and eventual evaporation or infiltration of a portion of the rainfall; therefore, available depression storage

Figure 3-11:

STORM SUBBASINS


UPPER MYSTIC LAKE WATERSHED
Aberjona River
MISHAWUM
Willow Bk
Halls Bk
Middlesex Canal
UNNAMED TRIBUTARIES
SWEETWATER
Aberjona River
HORN POND
Wittemore Pond
DIRECT RIVER
Sweetwater Brook
MURACO
Little Brook
Cummings Brook
Fowle Bk
Horn Pond
Shaker Glen Brook
Sucker Bk
Woburn Res
Winter Pd
Wedge Pd
Horn Pond Bk
Leonard Pool
HIGH-LAND
BOAT
Lake
GOLF
DIRECT LAKE
Upper Mys
1
0
1
miles

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36

is filled before runoff begins.

The simulation of runoff quality is done in two steps: (1) pollutant accumulation or build up on land surfaces is determined, and (2) pollutant washoff by precipitation is calculated. Pollutant loadings associated with runoff in STORM are assumed to be directly related to land use with pollutants accumulating on the land surface at a diminishing rate during dry periods. The accumulation process is represented by:

$$AC = Pmax \frac{HAFSAT}{(HAFSAT + t)^2}$$

where: AC = pollutant accumulation (lb/acre/day),
$Pmax$ = maximum accumulation of pollutants by land use (lb/acre /day),
$HAFSAT$ = time at which accumulation is half the maximum value (days), and
t = time since the last runoff ended (days).

Once the pollutant accumulation on each land use has been computed, the amount washed off during a given storm event is calculated by:

$$P_{L_{(t + \Delta t)}} = P_{L_t} e^{-kRt}$$

where: $P_{L_{(t + \Delta t)}}$ = pollutant load remaining at time $t + \Delta t$ (lb/acre),
P_{L_t} = pollutant load at time t (lb/acre)
k = washoff rate ($^1/$day),
R = rainfall intensity (in/hr), and
Δt = duration of runoff (days).

The rainfall record developed as described above, was linked to STORM and initiates the simulation process.

STORM Hydrology Calibration. Initial calibration efforts considered the entire Aberjona Watershed above the USGS gauging station as one basin and used seven years (1970-1976) of precipitation data from Logan Airport. Subsequent calibrations using the seven sub-basins used the three year period (1973-1975) to minimize computing time. Both were considered representative periods for precipitation.

For the Upper Mystic Lake Watershed, runoff coefficients for open space, residential and commercial/industrial land uses were 0.12, 0.23, and 0.46, respectively, with corresponding depression storage values of 0.4, 0.12, and 0.05 inches, respectively. These values were determined by CDM (1981a) for the MDC Mystic River Hydrology Study. Initial calibration results yielded an average runoff coefficient of 0.13 and a total runoff volume within four percent of the measured runoff at the USGS gauge during the calibration period.

For calibration at the more detailed sub-basin level, runoff coefficients were calculated for each sub-basin using the land use coefficients listed above. These derived coefficients were then compared to field measured data for three sub-basins: Sweetwater (IS3), Mishawum (IS1), and Unnamed Tributaries (IS2). The results of this calibration, presented in Table 3-8, compared favorably with initial calibration results. Summing results for the sub-basins, an average runoff coefficient of 0.14 for the three year simulation was obtained.

STORM Pollutant Loading Calibration. An effort was made to estimate buildup rates (Pmax) and HAFSAT values from field data. For each of the storms sampled, total pollutant load was compared with antecedent dry periods for the two end-of-pipe stations. Two types of antecedent dry periods were examined:

(1) the number of days since last measurable rainfall, and
(2) the number of days since last "flushing" rainfall (total precipitation exceeding 0.1 inches).

Total load for each storm was divided by drainage area and antecedent dry period to arrive at a buildup rate in pounds/acre/day. Results are presented in Table 3-9. In general, the buildup rates varied from storm to storm for most constituents. Representative buildup rates were selected for each land use type and adjusted to match program field data (see Tables 3-10 and 3-11).

To develop HAFSAT values from field data, total loads for each sampled storm, at four sampling sites, were plotted against antecedent dry period. Reliable HAFSAT values could not be developed using this method. The inconsistent results could be due to difficulty in estimating the true antecedent dry period, problems with composite sampling intervals or the inherent variability in urban runoff quality. Literature values were reviewed, and based on CDM's previous experience with STORM, a value of 2.0 was selected. This value assumes that buildup reaches half its maximum value after two days.

Reliable washoff rates could not be computed from the field data given the variability in loadings for each storm. The Users Manual for STORM suggests washoff rates between 1.0 and 4.6. After reviewing individual storm loads, a rate of 2.0 was selected.

Sensitivity analyses were conducted to assess the effects of varying HAFSAT, washoff rate, and buildup rate. In general, the amount of pollutant washed off was found to be most sensitive to buildup rate and less sensitive to the washoff rate than HAFSAT. Results are presented in CDM (1982).

Calibration of STORM was based on median concentrations measured for the seven sampled storms, as they are more representative of the actual observed loadings than mean loadings. A large June storm (June 22, 1981)

TABLE 3-8: RUNOFF COEFFICIENTS AND DEPRESSION STORAGE VOLUMES USED IN STORM STIMULATIONS

Subbasin	Average Field Measured Runoff Coefficient*	STORM Values Depression Storage (inches)	 Runoff Coefficient ***
Mishawum	0.17	0.27	0.20
Sweetwater	0.21	0.16	0.21
Unnamed Tribs.	0.14**	0.17	0.13
Muraco	NM	0.20	0.16
Horn Pond	NM	0.19	0.15
Highland	NM	0.20	0.15
Direct	NM	0.23	0.14
Gauge	0.11	0.20	0.14

NM = not measured

*Based on data collected for 7 Storms by EDP.

**Based on data collected at the Mill Street sampling site.

***Obtained from STORM output summaries by dividing total runoff volume by total rainfall volume.

Source: CDM, 1982.

TABLE 3-9: POLLUTANT BUILD-UP RATES AT END-OF-PIPE STATIONS

Date of Storm	Antecedent Dry Period-Time Since: Last Rain	Flushing Rain	POLLUTANT BUILD-UP[1] (lb/acre/day) TSS Last Rain	TSS Flushing Rain	TP Last Rain	TP Flushing Rain	PO_4 Last Rain	PO_4 Flushing Rain	NH_3 Last Rain	NH_3 Flushing Rain	NO_3 Last Rain	NO_3 Flushing Rain
ADDISON-WESLEY												
4/02/81	6	7	1.12	0.96	.0004	.0003	.0009	.0007	.0002	.0002	.013	.011
4/14/81	3	8	0.12	0.04	.0004	.0002	.0003	.0001	.0040	.0002	.007	.003
6/22/81	2	2	3.3	3.3	.0042	.0042	.0009	.0009	.0120	.0120	.058	.058
7/13/81	3	8	1.12	0.44	.0050	.0018	.0015	.0006	.0210	.0080	.046	.017
8/05/81	6	6	0.90	0.90	.0009	.0009	.0003	.0003	.0020	.0020	.009	.009
HEMLOCK ROAD												
4/14/81	3	8	0.18	0.07	.0015	.0006	.0012	.0005	--	--	--	--
6/20/81	8	11	1.16	0.84	.0043	.0031	.0021	.0015	.003	.002	.008	.006
6/22/81	2	2	0.09	0.09	.0020	.0020	.0009	.0009	.004	.004	.033	.033
7/13/81	3	8	0.63	0.24	.0030	.0011	.0022	.0008	.002	.002	.034	.012
8/05/81	6	6	3.81	3.81	.0270	.0270	.0122	.0122	.040	.040	.187	.187

[1] Build-up = (L/A)/t

where: L = Pollutant Load for Storm (lb)
A = Drainage area (acres)
t = Antecedent dry period (days)

[2] Flushing rain >0.1 in.

Source: CDM, 1982.

Table 3-10: BUILDUP RATES AND LAND USES FOR SUBBASINS WITH NO FIELD-MEASURED DATA

	LAND USE			BUILDUP RATES (lb/acre/mo)					
Subbasin	Open Space	Resi-dential	Commercial/ Industrial	TSS	PO_4	NO_3	TKN	TP	BOD
Barn	19%	69%	12%	6.0	0.01	0.4	1.0	0.06	4.5
Muraco	30%	60%	10%	9.0	0.01	0.3	0.5	0.02	1.4
Horn Pond	28%	65%	7%	9.0	0.02	0.6	0.5	0.03	1.4
Highland	30%	60%	10%	9.0	0.02	0.6	0.5	0.03	1.4
Direct Drainage (Aberjona)	40%	51%	9%	5.0	0.01	0.3	0.5	0.02	0.8
Golf Course	70%	25%	5%	5.0	0.07	0.6	0.5	0.11	0.8
Yacht Club	10%	60%	30%	12.5	0.04	0.3	0.5	0.06	1.9
Direct Drainage (Lake)	13%	63%	24%	12.5	0.07	0.3	0.7	0.11	1.9

Source: CDM, 1982.

Table 3-11: BUILDUP RATES USED IN STORM CALIBRATION FOR SUBBASINS WITH FIELD MEASURED DATA

	LAND USE			BUILDUP RATES (lb/acre/mo.)					
Subbasin	Open Space	Resi-dential	Commercial/ Industrial	TSS	PO_4	NO_3	TKN	TP	BOD
Hemlock	15%	85%	0%	12.5	0.04	0.6	0.5	0.06	1.9
Mishawum	38%	43%	19%	5	0.007	0.4	1.05	0.01	0.75
Sweetwater	15%	80%	5%	30	0.07	0.3	0.7	0.10	4.5

Source: CDM, 1982.

tended to raise mean concentrations to an uncharacteristically high value. The use of mean values would lead to an over-estimation of pollutant loads. and would misrepresent the urban runoff characteristics in the area.

The results were ultimately used as input to RWQM, which was calibrated against the observed instream concentrations. Sub-basin loadings were calculated for total suspended solids, biochemical oxygen demand, total kjeldahl nitrogen, nitrate, total phosphate, and orthophosphate. This also provided a second check on the validity of the model results.

An initial calibration was done for the Hemlock, Mishawum, and Sweetwater sub-basins. In each case STORM-generated average pollutant concentrations were within 15% of field measured median concentrations. Since washoff rates and HAFSAT values were held constant, the build up rates were manipulated to obtain a successful calibration. The selection of build up rates for the remaining sub-basins was done by comparing land uses to the three areas initially calibrated, using some judgement to account for unusual conditions such as high solids and phosphorus values due to combined sewer overflows in Sweetwater Brook.

In-stream Transport and Conditions

The data analysis consultants, Camp Dresser and McKee, simulated water quality conditions along the Aberjona River using the Receiving Water Quality Model (RWQM). STORM and RWQM were used sequentially with STORM providing runoff volumes and pollutant loads entering the Aberjona River from each of the seven sub-basins. The application of RWQM is described in detail by CDM (1982) and will only be briefly summarized in this section.

The specific objectives of the RWQM modeling analysis were:

(1) To determine seasonal and annual pollutant loadings to the Upper Mystic Lake, and

(2) To determine the impact of various control measures on those loadings.

Sources of pollutant loadings to the Upper Mystic Lake were divided into three components: dry weather flow, urban runoff, and sanitary contribution from Sweetwater Brook.

In addition to the use of RWQM, the water quality data collected on the Aberjona River and on the Boat Club and West Shore Inlets were compared to existing water quality standards and historical water quality data. Regression analysis was used in the historical comparison for selected parameters.

RWQM Description. RWQM simulates time-varying one dimensional hydraulic and water quality characteristics using the principle of conservation of mass:

39

$$\Delta M/t = I - O \pm S$$

where: ΔM = change in mass storage (lbs)
t = time period (hrs)
I = mass inflow rate (lb/hr)
O = mass outflow rate (lb/hr)
S = mass input rate from sources and sinks (lb/hr).

The Aberjona River was divided into six computational segments, as shown in Figure 3-12, based on hydrologic characteristics and the locations of major inflows. Figure 3-13 shows the relationship of these segments to the STORM sub-basins.

Hydraulic routing from segment to segment was computed using Mannings equation for open channel flow. A channel slope, width and roughness coefficient was assigned to each segment as determined by CDM (1981a) for the MDC Mystic River Hydrology Study (see Table 3-12). Normally associated with friction losses only, Mannings "n" values were used to represent other losses, such as storage, and consequently were a key parameter in the hydrology calibration. A sensitivity analysis was done for Mannings "n" and results are presented by CDM (1982).

In modeling water quality conditions, RWQM simulates four major physical mechanisms: advection, deposition, decay and die-off. While longitudinal dispersion is not simulated, it was not considered a major mechanism in the relatively well-mixed, swift-flowing Aberjona River. Only two constituents were modeled, phosphorus and total coliform. Other constituents simulated by STORM were not simulated with RWQM as in-stream sources and sinks of those constituents were not well defined.

Hydrology Calibration. Base flow was simulated as a continuous dry weather source from each STORM sub-basin as shown in Table 3-13. Wet weather flows were developed by STORM for each of the seven sub-basins. A six month period considered representative of normal flow conditions, was simulated. For that period, the average flow at the USGS gauge developed by the model was 22.6 cfs. The recorded average flow for that same period was 23.6 cfs.

Water Quality Calibration. The water quality calibration was also broken into dry and wet weather components. For baseflow phosphorus, a constant concentration of .04 mg/l was assigned to the Mishawum, Unnamed Tributaries, and Direct River sub-basins, and 0.07 mg/l to the remaining sub-basins. These values were derived from field data. Baseflow total coliform concentrations were assigned to each sub-basin individually based on field data.

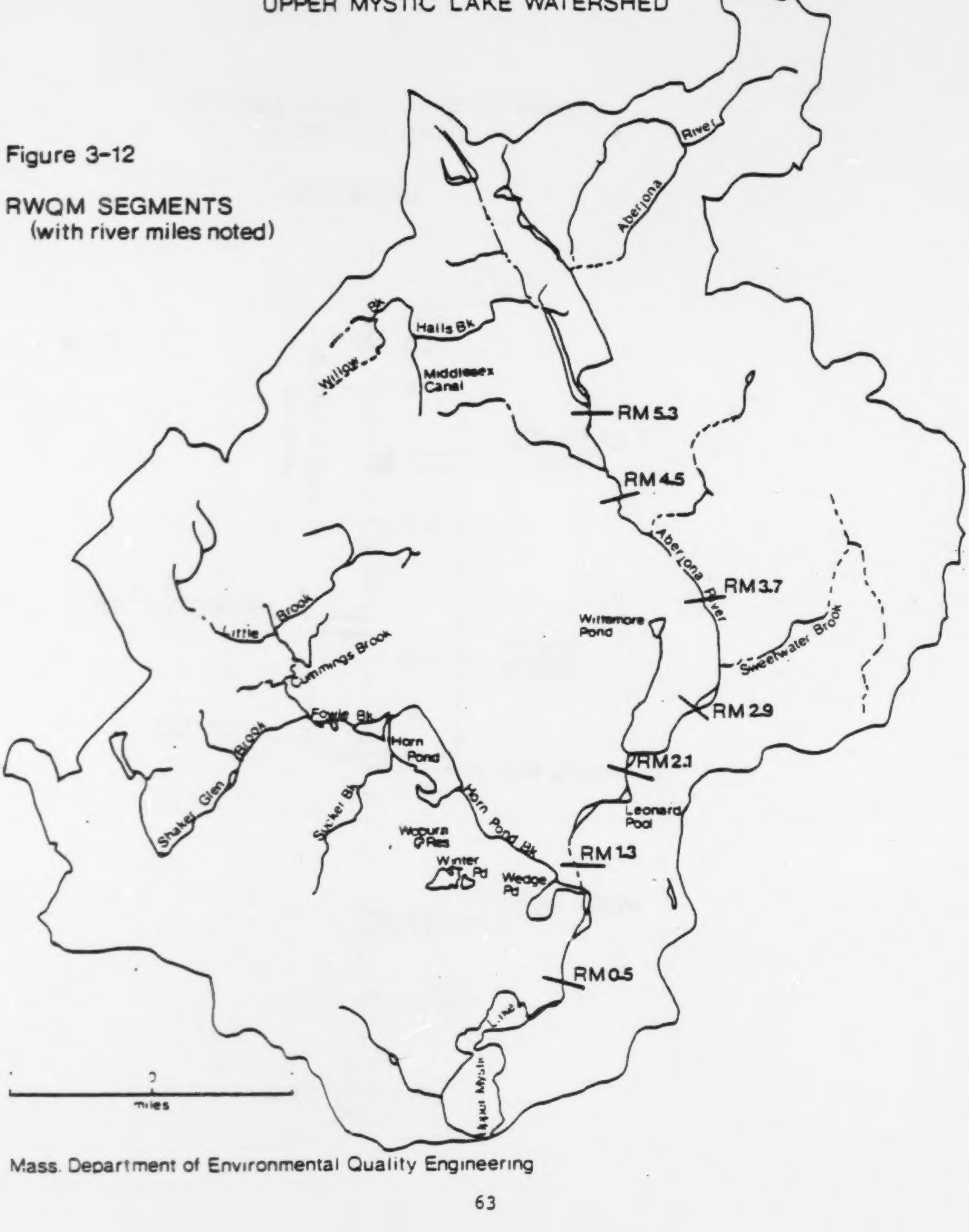
Wet weather phosphorus loads were developed by STORM. For total coliform, an average concentration of 10,000 MPN/100 ml was assigned to runoff based on field data. For Sweetwater Brook, where there are known sanitary connections, field data yielded an average value of 3,000,000 MPN/100ml.

Based on field data, a number of pollutant sinks along the Aberjona were identified:

UPPER MYSTIC LAKE WATERSHED

Figure 3-12

RWQM SEGMENTS
(with river miles noted)


Aberjona River
Halls Bk
Willow Bk
Middlesex Canal
RM 5.3
RM 4.5
Aberjona River
RM 3.7
Wittemore Pond
Sweetwater Brook
RM 2.9
RM 2.1
Leonard Pool
RM 1.3
RM 0.5
Little Brook
Cummings Brook
Fowle Bk
Horn Pond
Horn Pond Bk
Shaker Glen Brook
Sucker Bk
Woburn Res
Winter Pd
Wedge Pd
Upper Mystic
0
miles

Mass. Department of Environmental Quality Engineering

Figure 3-13: SPATIAL RELATIONSHIP OF STORM AND RWQM

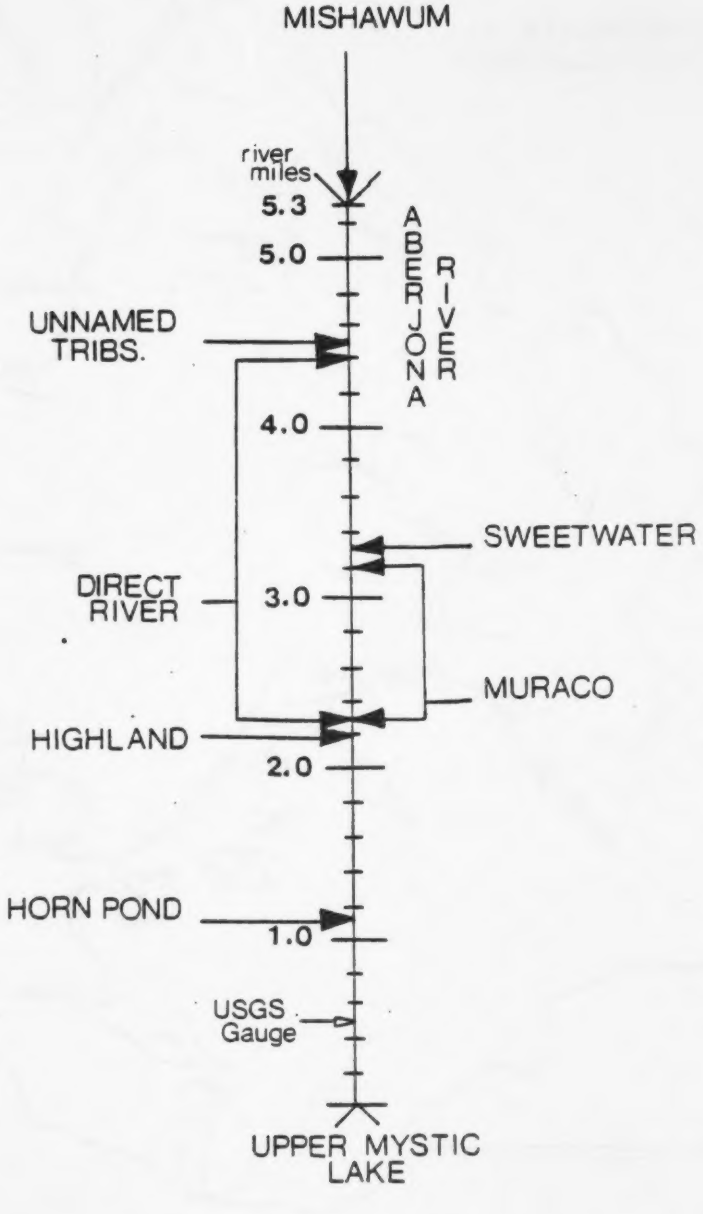

MISHAWUM
river miles
5.3
5.0
ABERJONA RIVER
UNNAMED TRIBS.
4.0
SWEETWATER
DIRECT RIVER
3.0
MURACO
HIGHLAND
2.0
HORN POND
1.0
USGS Gauge
UPPER MYSTIC LAKE

TABLE 3-12: HYDRAULIC PARAMETERS USED IN RWQM

River Mile	Channel Slope (ft/ft)	Roughness Coefficients	Width of Channel (ft)
4.9	0.004	0.45	15.0
3.7	0.001	0.5	17.0
2.5	0.002	0.5	25.0
0.9	0.002	0.35	35.0
0.5	0.001	0.4	35.0

Source: CDM, 1982.

TABLE 3-13: CONTRIBUTION TO BASEFLOW BY STORM SUBBASIN

STORM Subbasin	Drainage Area (acres)	Baseflow Contribution (cfs)
Mishawum	4,021	4.6
Barn	1,800	2.0
Sweetwater	1,450	1.6
Direct Aberjona	1,650	1.8
Muraco	620	0.7
Highland	620	0.7
Horn Pond	1,145	1.6
Total:		13 cfs

Source: CDM, 1982

(1) The meandering channel and swampy area between Mill Street and Olympia Avenue river crossings,

(2) The dam and pond upstream of the Washington Street crossing and downstream of the Sweetwater Brook confluence,

(3) The series of ponds/impoundments between the Swanton and Washington Street crossings, and

(4) Judkins and Mill Ponds behind the Winchester Town Hall.

In the coliform analysis first order exponential die-off was applied for total coliforms with a die-off rate of 1.1/day. A sensitivity analysis was performed for coliform die-off and volumetric sinks, and results are presented by CDM (1982). Table 3-14 presents calibration results for four locations along the Aberjona. The annual coliform simulation was done using average wet and dry concentrations.

Loading to the Upper Mystic Lake. RWQM was used to develop phosphorus and coliform loadings to the Lake. For the other constituents of concern, total suspended solids, (TSS), biochemical oxygen demand (BOD), total kjeldahl nitrogen (TKN), nitrate (NO_3-N), and ammonia (NH_3-N + NH_4-N), loadings were independently developed from field data collected at the USGS gauge and Sweetwater Brook. In addition, all the loadings for the Boat Club and West Shore Inlets were calculated in this manner.

In-lake Conditions

In general, as with the in-stream data, Lake water quality data were compared to various standards presented in Chapter 4.0, other guidelines found in the literature, historical data and data from other Massachusetts lakes. In addition, the distribution of water quality constituents within the Lake was considered, as were variations between wet and dry weather conditions. The more specific techniques used for certain parameters are presented below, along with details of the hydrologic analysis.

Hydrology and Morphology. The depth sounding data collected for the Lake were transcribed into a bathymetric map (Figure 3-5) and morphometric characteristics including depths, lengths, widths, slopes, areas, and volumes were calculated. An annual and seasonal hydraulic budget was then calculated using flow information and groundwater estimates developed by CDM.

Circulation patterns in the forebays and main basin were determined from dye study results. Visual and measured observations were transcribed and mapped. This information was also used to corroborate the retention time estimates for the forebays.

Nutrient Budgets. Nutrient budgets were developed for phosphorus and nitrogen using the loading data developed by CDM, the hydraulic budget as described above, and in-lake concentrations.

The sediment loading for phosphorus was calculated as:

TABLE 3-14: RWQM CALIBRATION RESULTS

LOCATION	Average Concentrations from Field-Measured Data Phosphorus (mg/l) Wet	 Phosphorus (mg/l) Dry	 Coliform (MPN/100ml) Wet	 Coliform (MPN/100ml) Dry	Average Concentrations from RWQM Simulation Phosphorus(mg/l)	 Coliform(MPN/100ml)
Mishawum Road	0.09	0.04	1,000	1,700	0.04	2,200
Mill Street	0.10	0.06	--	---	0.06	1,700
Washington Street	0.30	0.13	--	--	0.10	3,500
USGS Gauge	0.10	0.07	1,000	3,000	0.08	3,100

Source: CDM, 1982.

$$S = V(TP_2 - TP_1)\left(\frac{1\ \text{lb}}{454{,}500\ \text{mg}}\right)$$

where:
S = sediment load (lb/yr)
V = volume of anaerobic water (l)
TP_1 = mean concentration of total phosphorus in the hypolimnion before stratification (mg/l)
TP_2 = mean concentration of total phosphorus in the hypolimnion before fall turnover (mg/l).

This is a very rough calculation, and, in fact, represents the "worst case" situation. The major limitations of this calculation are:

(1) Since only three profile samples were collected - epilimnion, mid-metalimnion, and one-half meter above the sediments - a concentration gradient was estimated based on dissolved oxygen and temperature profiles and previous data. Ideally, samples should be taken every meter from the surface to the sediments.

(2) Samples were not taken immediately before stratification began nor immediately before fall turnover. May 1982 values were used for the former and November 1981 for the latter.

(3) The high iron concentrations found in the hypolimnion could be interfering with the analytical test for phosphorus. Unfortunately, that error cannot be quantified.

Trophic Status. CDM applied the Vollenweider (1975) input/output model to estimate the trophic status of the Lake as a result of varying levels of phosphorus loading. The model was applied to the entire Lake and to the main basin alone to analyze the characteristics of the latter by itself.

Sediment Classification. Two sediment ranking systems were applied to the data collected to determine the overall quality of the sediments: the Great Lakes Sediment Rating Index and the Sediment Pollution Index (SPI).

The Great Lakes Sediment Rating Index was developed by Region V of the U.S. Environmental Protection Agency. Sediments are classified as non-polluted, moderately polluted, or heavily polluted according to the criteria listed in Table 3-15. These are considered interim guidelines as they have not been sufficiently related to the actual impact of the sediments on a lake.

The Sediment Pollution Index (SPI) compares conditions encountered in a lake with sediment data from other areas. The SPI utilizes the Clarke Number (CN) which reflects the average natural occurrence of metals in the earth's crust, thus providing a basis for estimating the background level of metals in the sediments.

The CN reflects an average of all rock types within the earth's crust and one should expect a deviation from this number when sampling sediments in different areas since individual metals may occur more frequently at one location than another. However, the combined occurrence in the earth's crust of all the trace metals (Al, Fe, Mg, Mn are not included) is less than one tenth of one percent. Unless there are highly metallic geologic formations in the vicinity of a specific site, the natural occurrence of trace metals at that site is not expected to deviate significantly from the Clarke Number.

Metal content of unpolluted sediments is expected to be lower than those of un-weathered rock from the same area. The older the sediments and the more reactive the chemical environment, the higher are the rates of leachate of mineral metals from the sediments. Pollution-free sediments, composed of mainly inorganic matter (80% to 95%), are expected to contain metal concentrations less than or equal to those given by the Clarke Number. Sediments rich in organic matter are expected to contain metal concentrations greater than the Clarke Number. Consequently, sediments containing higher metal concentrations than indicated by the Clarke Number may be polluted (Mass. DEQE, 1981b).

A criterion for sediment metal pollution on a metal by metal basis based on the use of the Clarke Number can be formulated as:

$$\text{Pollution exists if } \frac{\bar{c}\text{ metal}}{\text{CN metal}} > f,$$

where: f = factor whose magnitude depends on the given metal,
$\bar{c}$ = mean concentration of the given metal, and
CN = Clarke Number of the given metal.

[illegible] ace metals (such as cadmium, chromium, selenium, arsenic, etc...) are [illegible] ted to deviate significantly from the Clarke Number, the f factor [illegible] nerally be less than two. For more common metals (such as iron and [illegible]), an f factor of one is sufficient since sediment concentrations of [illegible] re common metals rarely equals the Clarke Number. It is very crucial [illegible] asize that the f factor is extremely dependent on local geology as [illegible] e case of copper deposits, etc. The Clarke Numbers are listed in Table Table 3-16.

Application of this principle to a sample containing a number of metals can be formulated as:

$$\text{SPI} = \frac{1}{N} \sum_{i=1}^{N} \frac{\bar{c}i}{\text{CN}i},$$

where: SPI = Sediment Pollution Index,
N = Total number of metals included in calculating the SPI,
$\bar{c}i$ = Average concentration of metal i, and
CNi = Clarke Number of Metal i.

TABLE 3-15: GREAT LAKES SEDIMENT RATING CRITERIA
(mg/kg dry weight)

Constituent[1]	Nonpolluted	Moderately Polluted	Heavily Polluted
TKN	<1,000	1,000-2,000	>2,000
Lead	<40	40-60	>60
Zinc	<90	90-200	>200
Ammonia	<75	75-200	>200
Phosphorus	<420	420-650	>650
Iron	<17,000	17,000-25,000	>25,000
Nickel	<20	20-50	>50
Manganese	<300	300-500	>500
Arsenic	<3	3-8	>8
Cadmium	*	*	>6
Chromium	<25	25-75	>75
Copper	<25	25-50	>50
Mercury	*	*	≥1

* No lower limits defined.

Source: Mass. DEQE, 1981b.

TABLE 3-16: AVERAGE ABUNDANCES OF METALS IN EARTH'S CRUST "CLARKE NUMBER"

Metal	Clarke Number Earth's Crust mg/kg (ppm)
Ag	.07
Al	82,000
As	1.8
Ba	425
Cd	.1
Cr	100
Cu	55
Fe	56,000
Hg	.08
Mn	950
Ni	75
Pb	12.5
Se	.05
Zn	70

Source: Mass. DEQE, 1981b.

By adopting the SPI criterion as an indicator of pollution, a site is potentially polluted with (N) metals if:

$$SPI > F,$$

where the threshold factor, F, selected should take into account local background metal concentrations. In the case of Upper Mystic Lake, the threshold factor selected was F=10. This means that if the composite metal sample exceeded the composite CN by a factor of ten, the site may be considered polluted with metals. A factor of 10 was chosen based upon other Massachusetts lake and river SPIs where an SPI greater than 10 generally was associated with overall polluted conditions (sediments, water quality and biology included) (McGinn, 1982).

As with any multi-parameter index, the SPI has inherent advantages and disadvantages. The disadvantages are: that the SPI is limited to consideration of metals; it does not take into account differences in substrate type (i.e., sandy soils, clay or organic matter); it can mask extremely high levels of one metal in the presence of low levels of other metals used in the Index and it does not necessarily relate to sediment toxicity.

Advantages of the SPI are: a single number can be used to quantify the condition of a small sample or an entire site; it provides a quantitative means of comparing data from several other sites; and it provides a basis for qualitatively ranking the severity of metal pollution of sediments from several sites and/or different areas.

Control Evaluation

As the initial phase of control evaluation, an extensive review of various urban runoff control options was conducted which included an evaluation of general design considerations, control efficiencies, costs, and applicability to the Upper Mystic Lake Watershed. Regulatory control options applicable to Massachusetts communities were also considered. Additionally, in-lake control methods were similarly evaluated.

As discussed earlier, one of the advantages of using the RWQM model to evaluate in-stream transport was that it could subsequently be used to evaluate control strategies. By varying the pollutant loadings entering along the stream, corresponding reductions in loadings to the Lake can be calculated. This technique was used in the evaluation of controls for phosphorus. After revised phosphorus loadings were calculated, the Vollenweider trophic state model was used to determine the effect of reduced loadings on the Lake.

3.4 STATE, REGIONAL AND LOCAL COORDINATION

Coordination of the various state, regional and local interests in the Upper Mystic Lake Watershed was an integral element of this study, as the cooperation of those interests is essential to improving water quality in the Watershed.

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A complete review of the various state environmental water resource-related programs and authorities is beyond the scope of this discussion. Table 3-17 presents those of immediate relevance to the objectives of this project. At the regional level, the Metropolitan Area Planning Council is the officially designated regional planning agency for Greater Boston which includes the Upper Mystic Lake Watershed. Various local departments and boards also have interest in water quality in their community. These include: public works departments, engineering offices, boards of health, conservation commissions and planning boards. In addition to these government groups, the Mystic River Watershed Association (MRWA), a public interest group, is actively involved in water resource issues throughout the Mystic River Basin. The various agencies and groups described above were involved in development of the original workplan to varying degrees, and supplied technical support throughout the study.

The MRWA was awarded a contract to assist in coordinating public participation. Highlights of their work included: organizing volunteers to collect rainfall data, water quality samples, and to conduct a survey of fertilizer use; preparing newsletters and newspaper articles; and developing and showing a slide show about the project to civic organizations throughout the Watershed. The volunteer data collection program organized by MRWA is a new approach to public involvement and was successful in developing active interest in the project.

In order to keep local officials up-to-date on the project and solicit their advice, an advisory committee was established in March of 1981. Membership included one or two members appointed by each community in the Watershed, the Metropolitan Area Planning Council, and the Mystic River Watershed Association. The Committee met twelve times during the course of the study. A slide show was also prepared by the urban runoff staff and presented to several community agencies. Local officials were also polled regarding existing and desired future uses of water bodies in the communities and discussed in Chapters 2.0 and 4.0.

TABLE 3-17: MAJOR STATE INTERESTS IN THE UPPER MYSTIC LAKE WATERSHED

DEPARTMENT OF ENVIRONMENTAL QUALITY ENGINEERING (DEQE)	
Office of Planning and Program Management	Urban Runoff Project
Division of Hazardous Waste	Evaluation and clean-up of Industriplex site in Woburn; evaluation of Woburn landfill.
Division of Emergency Response	Evaluation and clean-up of Stephan area in Wilmington.
Division of Water Pollution Control	Administration of construction grants for wastewater treatment - current projects in Stoneham, Winchester and Arlington (Construction Grants Branch). Water quality monitoring and administration of Massachusetts lakes program (Technical Services Branch).
Northeast Regional Office	Enforcement of DEQE regulations.
DEPARTMENT OF FISHERIES WILDLIFE AND RECREATIONAL VEHICLES	
Division of Fish and Wildlife	Survey and stocking programs for Massachusetts lakes.
METROPOLITAN DISTRICT COMMISSION (MDC)	
Sewage	Planning and operation of MDC sewage collection and treatment systems.
Parks and Police	Planning, operation, maintenance, and surveilance of MDC park system including eastern shoreline of the Upper Mystic Lake.
Environmental Quality	Water quality monitoring at MDC beaches, lakes, and reservoirs and sanitary surveys of the major rivers within their juristiction.
Water	Planning, operation and maintenance of MDC water distribution system.

4.0 WATER QUALITY GOALS

The identification of water quality problems in this study was based on a comparison of existing water quality conditions with the requirements for certain uses. This included both existing uses which may be threatened by water quality conditions and desired uses which are precluded by those conditions. The following chapter covers the various water quality standards and criteria which have been developed for surface waters, and their relevance to water quality goals for the Upper Mystic Lake Watershed. The State and Federal regulations for general water quality parameters, guidelines for specific toxins, and criteria in regard to human health protection are presented. This will be followed by a discussion of local views on desired uses of these waters.

4.1 WATER QUALITY STANDARDS AND ADDITIONAL CRITERIA

State Standards

The Massachusetts Water Quality Standards, which are in compliance with Federal regulations, describe water quality requirements for inland waters in terms of their desired use. There are three classifications, but only two are presently of relevance to surface waters in the Upper Mystic Lake Watershed - Classes B and C (see Table 4-1). The Massachusetts Department of Environmental Quality Engineering's Division of Water Pollution Control (DWPC) has designated all surface waters in the Watershed as Class B, but their latest report indicates that all of the Aberjona River and its tributaries, as well as the Upper Mystic Lake itself, are below this desired quality level. In most cases they are also below the "C" level, and described as unsatisfactory (see Table 4-2). Based on the data collected under this project, conditions have for the most part not improved significantly since that time.

In addition to these standards, the State Sanitary Code includes regulations for bathing water quality for beaches (see Table 4-3). Any public areas where swimming is permitted must be sampled at least twice per month during the bathing season, but weekly monitoring is recommended.

Table 4-2. WATER QUALITY CLASSIFICATION FOR INLAND WATERS (M.G.L. Ch. 21, §27)

Class A = Waters assigned to this class are designated for use as a source of public water supply.

Class B = Waters assigned to this class are designated for the uses of protection and propagation of fish, other aquatic life and wildlife; and for primary and secondary contact recreation.

Class C = Waters assigned to this class are designated for the uses of protection and propagation of fish, other aquatic life and wildlife; and for secondary contact recreation.

For Class B Waters:		For Class C Waters:	
	Standards		
Parameter	Criteria	Parameter	Criteria
1. Dissolved Oxygen	Shall be a minimum of 5.0 mg/l in warm water fisheries and a minimum of 6.0 mg/l in cold water fisheries.	1. Dissolved Oxygen	Shall be a minimum of 5.0 mg/l in warm water fisheries and a minimum of 6.0 mg/l in cold water fisheries.
2. Temperature	Shall not exceed 83°F (28.3°C) in warm water fisheries or 68°F (20°C) in cold water fisheries, nor shall the rise resulting from artificial origin exceed 4.0°F (2.2°C).	2. Temperature	Shall not exceed 83°F (28.3°C) in warm water fisheries or 68°F (20°C) in cold water fisheries, nor shall the rise resulting from artificial origin exceed 4.0°F (2.2°C).
3. pH	Shall be in the range of 6.5-8.0 standard units and not more than 0.2 units outside of the naturally occurring range.	3. pH	Shall be in the range of 6.5-9.0 standard units and not more than 0.2 units outside of the naturally occurring range.
4. Fecal Coliform Bacteria	Shall not exceed a log mean for a set of samples of 200 per 100 ml, nor shall more than 10% of the total samples exceed 400 per 100 ml during any monthly sampling period, except as provided in Regulation 2.1.	4. Fecal Coliform Bacteria	Shall not exceed a log mean for a set of samples of 1000 per 100 ml, nor shall more than 10% of the total samples exceed 2,500 per 100 ml during any monthly sampling period, except as provided in Regulation 2.1.

Source: Massachusetts Department of Environmental Quality Engineering, 1978.

MDC Bathing Criteria

The Metropolitan District Commission established a policy for bathing water quality in 1982. Fecal coliform samples are collected weekly at all MDC beaches. If the fecal coliform count exceeds 500/100 ml a warning sign is posted and the beach is resampled. If coliform counts are between 201 and 500 the beach is resampled but not posted. The sign reads "Water Polluted Today - Swimming may be Hazardous" (DiPietro, 1982).

Additional Criteria

The standards discussed above are designed primarily to protect humans from contracting bacterial or viral infections, and to ensure that basic habitat requirements for fish populations exist. While these are concerns of the Mystic Urban Runoff Project, the impacts of urban runoff on aquatic environments may also include effects attributed to contaminants for which numerical standards are not specifically listed in the State water quality and sanitary regulations. The former regulations do, however, provide for consideration of other parameters, using EPA national criteria (U.S. EPA, 1976, 1980a) as guidelines.

In the following discussion, the currently available EPA National criteria will be presented with comments on their applicability to the Mystic Urban Runoff Project. Comparisons of the project data with these guidelines will be made in Chapter 6.0 of this report.

Table 4-2: UPPER MYSTIC LAKE WATERSHED WATER QUALITY CLASSIFICATION

Stream Segment	1980 Classification	1978 Condition
Aberjona River:		
- Headwaters to Hall's Brook	B	C
- Hall's Brook to Mishawum Road	B	U
- Mishawum Road to Mill Street	B	U
- Mill Street to Sweetwater Brook	B	U
- Sweetwater Brook to Washington Street	B	U
- Washington Street to Horn Pond Brook	B	U
- Horn Pond Brook to Upper Mystic Lake Inlet	B	U
Upper Mystic Lake:		
- Inlet to outlet	B	U

* "U" is no longer an official designation under the Water Quality Standards but is still used to denote unsatisfactory conditions.

Source: Massachusetts DEQE 1981.

Table 4-3: STATE STANDARDS FOR BATHING WATERS (M.G.L. Ch.30A, §127A)

10.1 GENERAL. Bathing shall not be permitted at any beach where the quality of bathing water does not meet the standards established in Regulations 10.2 and 10.3 of this article of the State Sanitary Code, and no bathing beach shall be established or maintained on a body of water when such water is determined by the Board of Health or the Massachusetts Department of Public Health to be polluted or so subject to pollution as to constitute a menace to health if used for bathing or swimming purposes.

10.2 PHYSICAL QUALITY. Bathing and swimming shall not be permitted in water areas when:

A. Sludge deposits, solid refuse, floating waste solids, oils, grease or scum are present, or
B. A black disk, 6 inches in diameter, on a white field placed at a depth of at least 4 feet of water is not readily visible from the surface of the water; or when under normal usage, such disk is not readily visible from the surface of the water when placed on the bottom where the water depth is less than four feet, or
C. A hazardous substance is or may be discharged into any bathing beach waters to a degree considered by the Board of Health or Massachusetts Department of Public Health to be of public health significance.

10.3 BACTERIOLOGICAL QUALITY. The water in bathing beaches shall be disapproved for bathig and swimming purposes when:

A. The result of a sanitary survey by the Board of Health or Massachusetts Department of Public Health discloses sewage or other hazardous substance is or may be discharged into the bathing beach waters to a degree considered by the Board of Health or the Massachusetts Department of Public Health to be a public health significance, or
B. Epidemiological evidence by the Board of Health or the Massachusetts Department of Public Health discloses the prevalence of an infectious disease which is considered as related to the use of bathing beach waters, or
C. The bacteriological quality of bathing beach water indicates that sewage or other hazardous substance is being discharged onto the bathing and swimming areas; or that high bathing density has created a condition which is or may be dangrous to the public health. A coliform count over 1,000 per 100 ml. shall be considered as a guide requiring additional investigation, survey or special analyses as maybe necessary.

Source: Massachusetts Department of Public Health, 1969.

Metals. Ambient water quality criteria for the protection of freshwater aquatic life from the effects of metal toxicity are listed in Table 4-4. The maximum or acute criteria is the concentration which killed 50% of the test population of 95% of the species tested during a 48 or 96 hour experiment. The 24 hour average or chronic criteria is based on a statistically significant adverse effect during a 28 day test.

In addition, EPA is currently preparing water quality standard guidelines for state review of standards for priority water quality areas. The EPA initiative calls for defining the attainability of certain uses and development of site specific criteria based on an environmental and economic assessment. These site specific criteria may be more or less sensitive than the national criteria. Massachusetts is currently reviewing its existing water quality standards and will be considering EPA's proposed methodologies.

For three of the metals, EPA criteria are not given. The toxicity of manganese to freshwater aquatic life is not considered to be a problem due to high tolerance levels, 1.5 to over 1,000 mg/l (U.S. EPA, 1976). The value listed in Table 4-4 was taken from water quality criteria developed by the State of California (McKee and Wolf, 1973). This was also the source for the aluminum guideline which pertains to fish populations only. Unfortunately, there is insufficient data on the toxicity of tin.

These twenty-four hour and maximum toxicity levels were generally developed assuming continuous exposure and are considered by some researchers to be overly protective when exposure is intermittent as is the case with urban runoff. While EPA has not adopted any formal wet weather criteria, they have as a part of the urban runoff program suggested such criteria for five metals (EPA, 1982). These estimated effect levels are shown on Table 4-4. The threshold level is the concentration at which some stress will be felt within the aquatic community, while the significant impact level was based on a 50% mortality in the organisms tested.

The bioaccumulation of metals in fish flesh is also of interest, particularly with regard to human consumption. Standards and criteria for acceptable levels of metals in fish tissues have not been widely documented, but EPA has published some criteria for the protection of consumers in terms of concentrations found in the water (U.S. EPA, 1980a).

As shown in Table 4-5, some of these values are based on the ingestion of both water and aquatic organisms. These criteria are over-protective for Upper Mystic Lake fish consumers since the lake water is not ingested by humans. In addition, EPA states that several of the guidelines do not represent values which directly affect human health since they are estimates of the level of a pollutant that will not produce unpleasant taste and odor during consumption of aquatic organisms (U.S. EPA, 1980a).

Priority Pollutants. Priority pollutant criteria have been developed by EPA for the protection of freshwater aquatic organisms and humans. Due to the large number of these contaminants, criteria for only those pollutants

Table 4-4: AMBIENT WATER QUALITY CRITERIA FOR METALS TO ENSURE PROTECTION OF FRESHWATER AQUATIC LIFE

Metal	24-hour Average Criteria (mg/l)	Maximum Criteria (mg/l)	Estimated Effect Level for Intermittent Exposure(mg/l)	
			Threshold	Significant Impact
Aluminum	———	0.25	———	———
Arsenic	———	0.44	———	———
Cadmium	0.00002	0.0024	0.0055	0.01
Chromium(III)	———	3.6970	8.6	———
Chromium(VI)	0.00029	0.021	———	———
Copper	0.0056	0.018	0.040	0.50
Iron	———	1.0	———	———
Lead	0.0023	0.1315	0.313	4.5
Manganese	———	1.0	———	———
Nickel	0.0808	1.5597	———	———
Tin	———	———	———	———
Zinc	0.047	0.2675	0.60	1.6

Sources: McKee and Wolf, 1973; U.S. EPA, 1976, U.S. EPA, 1980 a,c,d,e;*
U.S. EPA, 1982.

Table 4-5: AMBIENT WATER QUALITY CRITERIA FOR THE PROTECTION OF HUMAN HEALTH FROM THE TOXIC PROPERTIES OF METALS INGESTED THROUGH CONTAMINATED AQUATIC ORGANISMS

Metal	Exposure Type Used For Developing Criteria*	Criteria (mg/l)
Aluminum	———	not given
Arsenic	1	1.75×10^{-4}**
Cadmium	2	0.010
Chromium$^{(III)}$	1	3433
Chromium$^{(VI)}$	2	0.050
Copper	3	1.0
Iron	———	not given
Lead	2	0.050
Manganese	———	not given
Nickel	1	0.1
Tin	———	not given
Zinc	3	5.0

* Exposure Types

1: Based solely on consumption of 6.5 grams of fish and/or shellfish per day.

2: These values are the existing federal drinking water standards which are comparable to the calculated value for ingestion of contaminated water (2 liters/day) and organisms (6.5 grams/day).

3: These values are based on the available organoleptic data for controlling undesirable taste and odor in ambient water since there is insufficient data to calculate ingestion criteria.

** Based on a 10^{-5} incremental increase in cancer risk over a life

Source: U. S. EPA, 1980a.

detected in the Watershed are listed in Table 4-6 (see Chapter 5.0 for more information on detection). A number of metals are also priority pollutants including those indicated on Table 4-4. For some pollutants, EPA reported there was insufficient data to form a criterion.

Other Parameters. Table 4-7 lists criteria for several additional parameters not specifically found in the State standards. These criteria are based on protection of aquatic life with one exception. The phosphate-phosphorus guideline delineates the concentration above which nuisance aquatic growth may occur.

The ammonia criterion will be of particular interest in the discussion of water quality conditions. The 0.02 mg/l unionized ammonia criterion was calculated by applying a safety factor of 1/10 to the lowest lethal concentration cited in the literature, which was 0.20 mg/l. This value was reported for rainbow trout fry, the most sensitive species and lifestage tested (U.S. EPA, 1976). When applying this criterion the built-in safety factor should be recognized.

4.2 LOCAL WATER QUALITY GOALS

As previously discussed, the DEQE Division of Water Pollution Control has designated the Upper Mystic Lake Watershed as having Class B surface waters, reflecting the State and Federal goal of reaching and maintaining fishable and swimmable waters. Local support was strong at the time the designations were being determined, and is in part responsible for the basin-wide B rating. It was made apparent through surveys that the public wanted to use surface waters for recreational purposes.

As part of this project, a questionnaire designed to obtain current information relevant to present and desired uses of local surface water was distributed to conservation commissions, planning boards and recreation departments in 1981. A complete list of respondents is shown in Table 4-8. The responses indicated a definite desire to preserve and improve the quality and recreational value of basin surface waters. A comparison of current uses, discussed in Chapter 2.0 and listed in Table 2-7, with desired uses, showed very few changes. All changes are shown on Table 4-9.

Factors affecting use impairment and specifics about water quality were also probed. Most respondents felt that poor water quality impaired the desired use of waters within the Watershed, with pollution stemming from both upstream and local sources. Some water bodies suffered from neglect; others were over-used. Other common problems affecting use dealt with inaccessibility to the water and the lack of adequate recreational facilities. Low flow in the Aberjona River was also felt to impair desired uses. Table 4-10 summarizes the local opinions of problems affecting major water bodies in the Watershed. Respondents were also asked what factors they felt had helped to improve water quality over the past five years. Responses included federal and state regulations, local regulations and public awareness.

Table 4-6: CRITERIA FOR PRIORITY POLLUTANTS

Priority Pollutant	Protection of Freshwater Aquatic Organisms*		Protection of Humans From Ingestion of Contaminated Organisms (μg/l)
	Acute Threshold (μg/l)	Chronic Threshold (μg/l)	
1,2-dichloroethane	118,000	20,000	2,430**
1,1,1-trichloroethane	18,000	not given	1.03×10^6
1,1-dichlorethane	not	given	insufficient data
1,1,2-trichloroethylene	18,000	9,400	418**
chloroethane	not	given	insufficient data
1,1-dichloroethylene	11,600	insufficient data	18.5**
1,2-trans-dichloroethylene	11,600	insufficient data	insufficient data
ethylbenzene	32,000	insufficient data	3,280
tetrachloroethylene	5,280	840	88.5**
toluene	17,500	insufficient data	424,000
trichloroethylene	45,000	insufficient data	807**
vinyl chloride	insufficient	data	5,246**
chlordane	0.0043*	2.4*	0.0046**
phenol	10,200	2,560	3.500
1,2-dichlorobenzene	1,120	763	2,6000
phthalates	940	3	not given
diethyl phthalate			1.8×10^6
pyrene	not	given	not given

* All values, except for chlordane, are "apparent threshold levels" which reflect the points where acute and chronic effects are exhibited in some species. In these cases there was insufficient data available to allow the derivation of criteria. Chlordane values listed are the "24-Hour Average" (acute threshold) and "maximum" (chronic threshold) criteria.

** These values reflect an estimated 10^{-5} incremental increase in cancer risk over a lifetime.

Source: U. S. EPA, 1980a.

Table 4-7: ADDITIONAL AMBIENT WATER QUALITY CRITERIA

Parameter	Criteria (mg/l)
Ammonia Nitrogen (Unionized)	.02
Nitrite - Nitrogen	.06*
Alkalinity	20 (Minimum)
Phosphate- Phosphorus	.025*
Oil and Grease	Bioassay Required
Solids	Site Specific

* Not accepted as formal criteria but cited by the source from available literature.

Source: U. S. EPA, 1976.

Table 4-8: RESPONDENTS TO SURFACE WATER USE QUESTIONNAIRE

Mystic River Watershed Association
Arlington, Natural Resources Division
Arlington, Office of Planning and Community Development
Arlington, Recreation Department
Arlington, Recreation Facilities Committee
Arlington, Spy Pond Study Committee
Medford, Office of Community Development
Reading, Board of Health
Reading, Conservation Commission
Reading, Public Works
Reading, Recreation Committee
Stoneham, Engineering Department
Wilmington, Conservation Commission
Winchester, Conservation Commission
Winchester, Department of Recreation
Winchester, Planning Board
Woburn, Conservation Commission

Table 4-9: DESIRED FUTURE USES OF MAJOR WATER BODIES -- SURVEY RESULTS

Surface Water Area	Current Use(s) Not Listed As Future Use	Additional Future Use(s) Desired
Aberjona River (Headwaters to Route 128)	---	Swimming Waste Assimilation Water Supply
Hall's Brook	---	Non-motor boating Warm water fishing
Middlesex Canal	---	---
Aberjona River (Route 128 to Sweetwater Brook)	---	Non-motor boating Warm water fishing
Aberjona River (Sweetwater Brook to Wedge Pond)	---	Warm water fishing
Leonard Pool	---	Conservation Area
Shaker Glen Brook	---	---
Horn Pond	---	---
Horn Pond Brook	Flood Control	---
Winter Pond	---	Conservation Area Swimming
Wedge Pond	Flood Control	Conservation Area
Long Pond	---	Warm water fishing
Aberjona River (Wedge Pond to Upper Mystic Lake)	Flood Control	Non-motor boating Warm water fishing
Judkins Pond	---	---
Mill Pond	Flood Control	---
Upper Mystic Lake	---	Cold water fishing Motor boating

From these views and the interest shown throughout this project, the local officials and residents have indicated a continuing desire to achieve Class B waters, particularly for Upper Mystic Lake itself. This opinion gives support to the objectives of the Mystic Urban Runoff Project, and provides a basis for the evaluation of control options.

Table 4-10: FACTORS AFFECTING USES OF MAJOR SURFACE WATER BODIES - SURVEY RESULTS

Surface Water Area	Factor(s) Impairing Use	Surface Water Area	Factor(s) Impairing Use
Aberjona River (Headwaters to Route 128)	Low Flow Over-Use Poor Water Quality • Local Pollution Sources	Wedge Pond	Inadequate Recreational Facilities Neglect Poor Water Quality
Hall's Brook	Poor Water Quality	Long Pond	Inadequate Recreational Facilities Insufficient Access
Aberjona River (Route 128 to Sweetwater Brook)	Poor Water Quality	Aberjona River (Wedge Pond to Upper Mystic Lake	Inadequate Recreational Facilities Insufficient Access Low Flow Neglect Poor Water Quality • Local Pollution Sources • Upstream Pollution Sources
Aberjona River (Sweetwater Brook to Wedge Pond)	Inadequate Recreational Facilities Insufficient Access/ Surrounding Land Primarily Privately Owned Low Flow Neglect Poor Water Quality • Local Pollution Sources • Upstream Pollution Sources	Judkins Pond	Neglect Poor Water Quality • Upstream Pollution Sources
Leonard Pool	Low Flow Neglect Over-Use Poor Water Quality	Mill Pond	Inadequate Recreational Facilities Low Flow Neglect Poor Water Quality • Upstream Pollution Sources
Shaker Glen Brook	Low Flow	Upper Mystic Lake	Insufficient Access/ Surrounding Land Primarily Privately Owned Over-Use • Local Pollution Sources • Upstream Pollution Sources
Horn Pond Brook	Neglect		
Winter Pond	Inadequate Recreational Facilities Inadequate Surface Area Insufficient Access/ Surrounding Land Primarily Privately Owned Poor Water Quality		

5.0 SOURCES OF POLLUTION

One of the primary objectives of this project was to characterize urban runoff pollution in the Watershed. To do this effectively, an investigation of all pollution sources in the Watershed was necessary so that the amount of pollutants contributed by urban runoff could be separated from other contaminants. A detailed discussion of urban runoff will be followed by a brief description of other known sources.

5.1 SOURCES AND CHARACTERISTICS OF URBAN RUNOFF POLLUTION

The types of runoff contaminants which end up in stormwater vary greatly, and determining their origin is often difficult. Studies have, however, linked some runoff pollutants with their sources. This section will discuss these sources, and the specific characteristics of urban runoff in the Upper Mystic Lake Watershed.

Sources

The contaminants found in stormwater can be traced to specific sources such as automobiles, fertilizers, soils, litter, the atmosphere, leaves, and other plant materials. Table 5-1 lists common runoff pollutants and the sources from which they usually originate. Although these contaminants are regularly found in runoff, their quantity varies geographically due to factors such as land use, climate, and geology. Although each watershed is unique, comparisons can be made between similar areas.

Runoff Characteristics in the Upper Mystic Lake Watershed

One of the primary objectives of this project was to identify the characteristics of local runoff. In-stream and end-of-pipe stations supplied the data used to characterize stormwater runoff in the Watershed.

TABLE 5-1: URBAN RUNOFF POLLUTANTS AND MAJOR SOURCES

POLLUTANT	SOURCES
Aluminum	soils
Arsenic	herbicides, soils
Cadmium	soils, tires
Chromium	atmospheric deposition, engine plating, soils
Copper	brake linings, engine plating, pesticides, soils
Iron	rust, soils
Lead	leaded fuels, motor oils, soils, tires
Manganese	fertilizers, motor oils, soils
Nickel	engine plating, soils
Nitrogen Compounds	atmospheric deposition, fertilizers, plant materials, tires
Oil and Grease	hydraulic fluids, motor oils
Oxygen Demanding Compounds (measured as BOD)	organic matter
Phosphorus Compounds	atmospheric deposition, fertilizers, plant materials
Solids	atmospheric deposition, erosion, road abrasion, road sanding
Zinc	motor oils, soils, tires

Sources: Graber, 1978.
U.S. EPA, 1976.
U.S. EPA, undated.

The two end-of-pipe (EOP) stations were established to measure runoff quality and quantity from a small area with one type of land use. The stations, located at Hemlock Road and at the Addison-Wesley parking lot in Reading represent residential and commercial/industrial land uses, respectively, as described in Section 3.2. Summaries of wet weather loads and concentrations for these two stations can be found on Tables 5-2 and 5-3. All the data can be found in Appendix A. Unfortunately, problems developed in the incubation of most of the bacteria samples collected and, consequently, no representative data is available. Initially, these data were examined to determine general runoff characteristics, such as those discussed below.

First Flush. The rate at which pollutants are washed off of a land surface is dependent on a number of factors including land use, storm intensity, and pollutant characteristics. In first flush, pollutant concentrations in runoff are higher during the first part of a storm as they are effectively being flushed from the land surface. To determine if a parameter exhibited first flush effects in this study, the composite concentrations were plotted against the percentage of total storm runoff that had occurred up to the time the composites were taken. If the curve illustrated high initial concentrations followed by a gradual decline, a first flush was evident. Data from the EOP's Mishawum Road, Washington Street, and the USGS Gauge were analyzed, as these stations either measured runoff alone or were located at the base of a STORM sub-basin.

Not all storms were included in the first flush analysis. The sampling of many storms was stopped before all the runoff flow had passed, or in some cases the first composite represented a disproportionate amount of the total runoff making it impossible to see flush patterns. The later problem was often the case at Sweetwater Brook and Addison-Wesley. First flush analysis was also not done for metals due to an insufficient data base. A plot which illustrates the flushing effect is shown in Figure 5-1; the remaining plots are included as Appendix B. For most stations, first flush effects were observed for total suspended solids and phosphorus species (see Table 5-4). The concentrations of nitrogen compounds tended to remain constant throughout the storm. No first flush was observed at the USGS station, probably due to the cancelling of the many tributary loads.

A first flush analysis can be used to indicate if treatment of only the first portion of the runoff generated will effectively reduce the pollutant load. For this Watershed, only solids and phosphorus would be reduced by this practice. Treatment of all the runoff would be required to lower nitrogen contributions to the same degree.

Particulate and Dissolved Fractions. A constituent can exist in an aquatic system in either the particulate or dissolved form. Dissolved substances are often hard to control, while the particulate fraction is easier to remove from the water column. By determining what percentage of a parameter is in each form, the effectiveness of control options which remove solids can be assessed.

Nitrogen and phosphorus were analyzed for particulate and dissolved fractions. At the EOP stations the runoff contained 60% to 70% dissolved phosphorus

TABLE 5-2: SUMMARY OF LOADS AND CONCENTRATIONS FOR THE HEMLOCK ROAD END-OF-PIPE STATION

	Load (lbs/storm)			Average Concentration (mg/l)		
Constituent **	Range	Mean	Median	Range	Mean	Median
BOD	8 - 40	17	9	0.7 - 47	9.8	4.3
TSS	9 - 1143	348	295.8	7 - 2249	508	62.5
VSS	10 - 487	249	249	3.5 - 958	481	41.0
TP(N)*	0.18 - 8.24	2.2	0.46	0.08 - 16.2	3.5	0.3
TP(F)*	0.07 - 5.88	1.5	0.21	0.05 - 11.5	2.4	0.2
PO_4(N)	0.09 - 3.68	1.0	0.33	0.06 - 7.2	1.6	0.2
PO_4(F)	0.07 - 3.59	1.0	0.18	0.05 - 7.1	1.5	0.1
NO_3(N)	3.2 - 56.2	17.0	4.2	1.5 - 110.6	29.5	2.9
NH_3(N)	0.35 - 12.0	3.5	0.8	0.2 - 24	6.3	0.4
NH_3(F)	0.16 - 8.0	2.3	0.6	0.02 - 16	4.1	0.25
TKN(N)	4.0 - 124.0	40.8	16.82	3.1 - 224	68.3	13.0
TKN(F)	1.9 - 56.1	25.5	22.0	1.25 - 110	31.7	7.8
Al	0.4 - 3.6	1.7	1.5	.3 - 1.8	1.35	1.65
Cu	0.04 - 0.4	0.18	0.13	.03 - .17	.132	.165
Zn	0.06 - 0.4	0.23	0.23	.13 - .27	.175	.15
Pb	0.04 - 0.4	0.19	0.16	.03 - .23	.155	.18
Ni	.012 - .08	.04	.04	.02 - .06	.037	.03
Fe.	0.04 - 3.8	2.1	2.1	.3 - 2.6	1.7	1.95
Mn	0.16 - 1.2	0.54	0.39	.12 - .54	.398	.465
As	ND - .021	.008	.006	<.001 - .017	.008	.0075
Sn	ND - .03	.011	.007	<.005 - .076	.022	.0055
Cr	.005 - .005	.005	.005	.012 - .012	.012	.012
Cd	ND - .013	.004	ND	<.01 - 0.1	.003	<.01

* (N) = Nonfiltered (F) = Filtered
ND = Not Detected
** Abbreviations listed on Table 3-4.

Source: CDM, 1982

Table 5-3: SUMMARY OF LOADS AND CONCENTRATIONS FOR THE ADDISON-WESLEY END-OF-PIPE STATION

	Load (lbs/storm)			Average Concentration (mg/l)		
Constituent	Range	Mean	Median	Range	Mean	Median
BOD	2.3 - 11.1	5.5	4.4	1.0 - 8.9	4.6	4.2
TSS	6.3 - 121	63.9	63	19.5 - 79.2	45.5	30
VSS	1.78 - 20.3	8.7	4.1	5.5 - 13.3	9.0	8.3
TP(N)*	0.022 - 0.15	0.11	0.1	0.03 - 0.1	0.1	0.1
TP(F)*	0.017 - 0.17	0.075	0.061	0.015- 0.1	0.06	0.07
PO_4(N)	0.017 - 0.093	0.055	0.057	0.02 - 0.06	0.05	0.05
PO_4(F)	0.011 - 0.015	0.05	0.023	0.015- 0.07	0.04	0.03
NO_3(N)	0.39 - 2.5	1.47	1.41	0.1 - 1.4	1.1	1.2
NH_3(N)	0.2 - 1.14	0.47	0.37	0.03 - 0.7	0.37	0.4
NH_3(F)	0.13 - 0.97	0.39	0.33	0.02 - 0.5	0.29	0.3
TKN(N)	0.5 - 7.42	2.92	2.7	1.0 - 3.5	2.0	1.8
TKN(F)	0.35 - 2.57	1.16	0.85	0.8 - 1.2	1.0	1.1
Al	0.13 - 5.4	2.4	1.8	1.2 - 2.8	1.9	1.7
Cu	.008 - .3	.17	0.2	.1 - .22	.143	.11
Zn	.014 - 3.5	1.2	0.2	.1 - 2.3	.863	.19
Pb	.017 - .4	.19	.15	.1 - 2.3	.177	.2
Ni	.002 - .08	.04	.04	.02 - .05	.035	.035
Fe	.17 - 7.5	3.1	1.7	1.1 - 3.9	2.43	2.3
Mn	.002 - .4	.16	.08	.05 - .25	.17	.21
As	ND - .015	.005	ND	<.001 - .008	.005	.007
Sn	.002 - .15	.084	.1	.028 - .07	.05	.053
Cr	.0008 - .0008	.0008	.0008	.01 - .01	.01	.01
Cd	ND	-	-	ND	-	-

* (N) = Nonfiltered (F) = Filtered
ND = Not Detected

Source: CDM, 1982

Figure 5-1: FIRST FLUSH PLOT

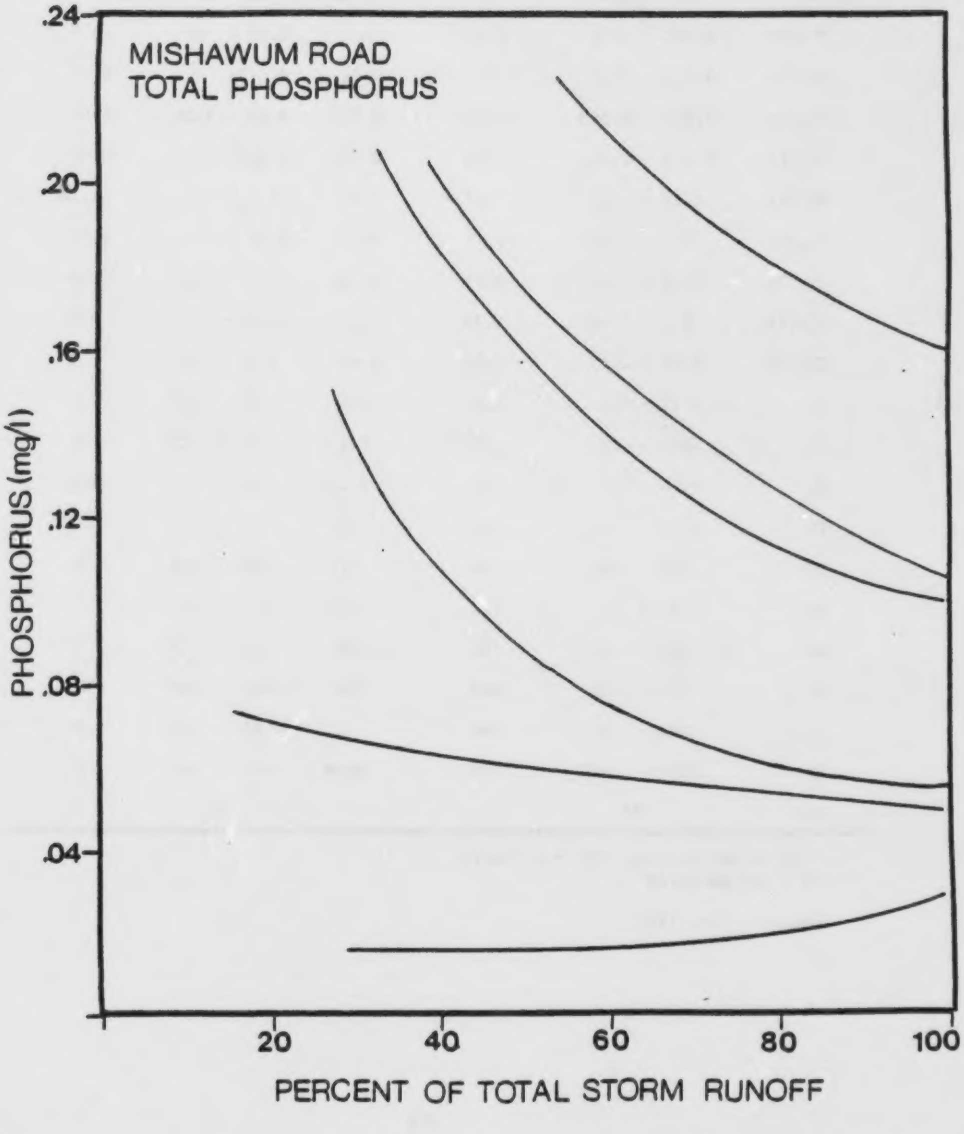

TABLE 5-4: CONCLUSIONS OF FIRST FLUSH ANALYSIS

Station	Exhibited First Flush	Remained Constant	Increased
Hemlock Road	TSS, TP, PO_4	TKN, NH_3, NO_3	---
Addison-Wesley	TP, PO_4	TSS, TKN, NH_3, NO_3	---
Mishawum Road	TSS, TP, PO_4	TKN, NH_3, NO_3	---
Washington Street	TSS, TP, PO_4	TKN, NO_3	NH_3
USGS Gauge	---	TSS, TP, PO_4, TKN, NH_3,NO_3	---

Source: CDM, 1982.

compounds (TP and PO_4-P). This indicates that a maximum of 30% to 40% of the total phosphorus load could be controlled by treatments which concentrate on solids removal. The in-stream dissolved phosphorus fraction was slightly lower with a range of 40% to 50% dissolved, making solids removing treatments slightly more effective on these waters.

Most of the nitrogen present was in the dissolved form. For both EOP and in-stream stations, 80 to 90% of the ammonia was dissolved. Eighty percent of the TKN was dissolved within the river, but only 60% of the EOP TKN was in solution. This indicates that 10 to 20 % of the nitrogen in-stream and 20 to 40% in the runoff could be removed through solids control. These fractions, for both phosphorus and nitrogen compounds, were well within ranges observed elsewhere in the United States (CDM, 1982).

Comparison with Other Runoff Data. CDM's analysis of the EOP data found the nutrient, BOD, bacteria, and metals concentrations to be within the normal ranges found in runoff elsewhere in the country (see Table 5-5).

Priority Pollutant Analysis. EOP samples were analyzed for priority pollutants. Table 5-6 shows which pollutants were detected in the EOP samples as well as the trip blanks. Only two contaminants found in the runoff samples were not found in the blanks - diethyl phthalate at Hemlock Road and pyrene at Addison-Wesley. The diethyl phthalate appears to be present in low levels in comparison to the EPA criteria of 940 and 3ug/l for the protection of aquatic life against acute and chronic toxicity, respectively. The concentration is also below the guideline of 1.8×10^6ug/l for protecting humans against toxicity from consuming contaminated organisms. Criteria for pyrene were not available, thus conclusions regarding the toxicity of this compound cannot be made at this time. Chapter 4.0 contains a more detailed discussion of these criteria.

Table 5-5: COMPARISON OF END-OF-PIPE CONCENTRATIONS WITH LITERATURE VALUES
(mg/l)

End-of Pipe Median Concentrations

Stations	TP	TKN	NO_3-N	NH_3-N
Hemlock	0.3	13.0	2.9	0.3
Addison-Wesley	0.1	1.8	1.2	0.4

Literature Values

	TP		TKN		NO_3-N		NH_3-N	
Land Use	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range
Light Industry	0.2	.01-1.5	1.4	0.5-3.6	1.2	0.1-4	0.4	0.1-1.3
Commercial	0.2	.02-2.2	2.0	0.8-4.5	1.6	0.3-3	0.5	0.1-1.3
Single Family	0.14	.01-0.7	1.7	0.4-8	1.4	0.1-7	0.5	0.1-2.3
Multi-Family	0.23	.04-0.7	2.1	1.3-7.4	1.1	0.2-3	0.5	0.1-2.2

Source: CDM, 1982

Table 5-6: END-OF-PIPE PRIORITY POLLUTANT DATA
(all concentrations at 1-9 ug/l)

9/17/81	Priority Pollutants Found
Hemlock Road	1, 2 dichlorobenzene diethyl phthalate
Trip Blank	1, 2 dichlorobenzene bis (2-ethylhexyl) phthalate
9/23/81	
Hemlock Road	2, 4 dichlorophenol bis (2-ethylhexyl) phthalate butyl benzyl phthalate diethyl phthalate
Addison-Wesley	2, 4 dichlorophenol bis (2-ethylhexyl) phthalate pyrene
Trip Blank	2, 4 dichlorophenol bis (2-ethylhexyl) phthalate butyl benzyl phthalate diethyl phthalate

Long-term Runoff Characteristics

The second phase of the runoff analysis examined long-term runoff characteristics. To do this, the quantity and quality of runoff generated in the Watershed was modeled using STORM as described in Section 3.3.

The main outputs provided by STORM are the average annual and seasonal washoff loads for each sub-basin. These loads reflect the level of contamination being transported to the Aberjona River in stormwater runoff. Annual washoff loads for total suspended solids, nitrate, total Kjeldahl nitrogen, orthophosphate, total phosphorus, and biochemical oxygen demand are summarized for each sub-basin of the Aberjona River on Tables 5-7.

Table 5-8 shows the average annual washoff loads of these parameters in lbs/acre. These numbers indicate the relative pollutant contribution from each sub-basin, as area differences are taken into consideration. One must remember that much of the Horn Pond sub-basin was excluded from the analysis since flow to the Aberjona River occurred infrequently. Also, the type of data collected required high nitrogen levels from industrial sources above Mishawum Road, be included in the washoff loads in order to accurately calibrate the model. This influences artificially elevated the load actually attributed to runoff. Comparison of the annual washoff loads per acre, excluding Mishawum Road, shows consistency between sub-basins. The ranges for most constituents are narrow. The comparison between these loads and other sources of pollution is discussed in Chapter 6.0.

The information generated by STORM was used in the Receiving Water Quality Model (RWQM) to calculate the annual loads for phosphorus and total coliform from the Aberjona River to Upper Mystic Lake. Loads for other constituents and from the other two tributaries and direct drainage to the Lake were calculated based on field data collected. These results are included in Chapter 6.0.

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Table 5-7: AVERAGE ANNUAL POLLUTANT WASHOFF BY SUBBASIN*

	Washoff(lbs)					
Subbasin	TSS	NO_3-N	TKN	PO_4-P	TP	BOD
Mishawum	210,715	16,857	44,251	295	505	31,605
Unnamed Tributaries	77,565	5,171	12,928	128	215	11,635
Sweetwater % CSO	464,100 90%	4,641 75%	10,828 60%	1,083 75%	1,720 75%	69,615 80%
Direct River	65,442	3,926	6,545	91	155	9,815
Muraco	48,651	1,621	2,703	39	65	7,300
Highland	47,119	3,141	2,618	131	185	7,065
Horn Pond	87,444	5,829	4,858	242	340	13,115

*based on STORM 3-year simulation

Table 5-8: AREAL AVERAGE ANNUAL POLLUTANT WASHOFF

(lbs/acre/yr)

Subbasin	TSS	NO_3-N *	TKN *	PO_4-P	TP	BOD
Mishawum	52.4	4.2	11.0	0.07	0.12	7.9
Unnamed Tributaries	43.1	2.9	7.2	0.07	0.12	6.5
Sweetwater-CSO	288.1	2.4	4.5	0.56	0.89	38.4
- urban runoff	32.0	0.8	3.0	0.19	0.30	9.6
Direct River	39.7	2.3	4.0	0.06	0.09	5.9
Muraco	78.5	2.6	4.4	0.06	0.10	11.8
Highland	76.0	5.0	4.2	0.21	0.30	11.4
Horn Pond	76.3	5.1	4.2	0.21	0.29	11.5

Source: CDM, 1982.

5.2 OTHER SOURCES OF POLLUTION

There are several sources of pollution present in the Upper Mystic Lake Watershed other than urban runoff. Industries, municipalities, and even natural sources contribute to the load of pollutants entering surface waters. Many of these sources have been identified and their locations can be seen on Figure 5-2. Unfortunately, the quantity of pollutants emanating from several of these sources has not been determined.

Non-Point Sources

The non-point sources of pollution in the Watershed, excluding urban runoff, are mainly related to past and present industrial waste disposal practices in the Upper Watershed. One major area of concern is the D'Annolfo property, commonly referred to as the Industri-plex site, located just north of Route 95 in Woburn near the former site of Mishawum Lake. Recently, during preparation of the land for new industrial development, waste deposits from past industries were uncovered.

Animal hides buried in the mid-1900's by glue manufacturers were excavaded and piled elsewhere on the site. The decaying hides created an odor problem which was brought to the attention of the Massachusetts Department of Public Health by nearby residents. After inspection of the site, notices of air pollution violations were issued. The extent and severity of the problem was not realized until 1979 when EPA discovered waste deposits with high concentrations of arsenic, lead and chromium. Other contaminants detected at the site include aluminum, antimony, copper, iron, manganese, nickel, sodium, strontium, tin, titanium, zinc and zirconium (Tufts University, Department of Urban and Environmental Policy, 1980). For more than 100 years, wastes have been disposed of at the site. A brief history of land use in the area is outlined in Table 5-9. The severity of the problem was acknowledged by EPA when the site was ranked in the top ten on their list of hazardous waste sites in the country.

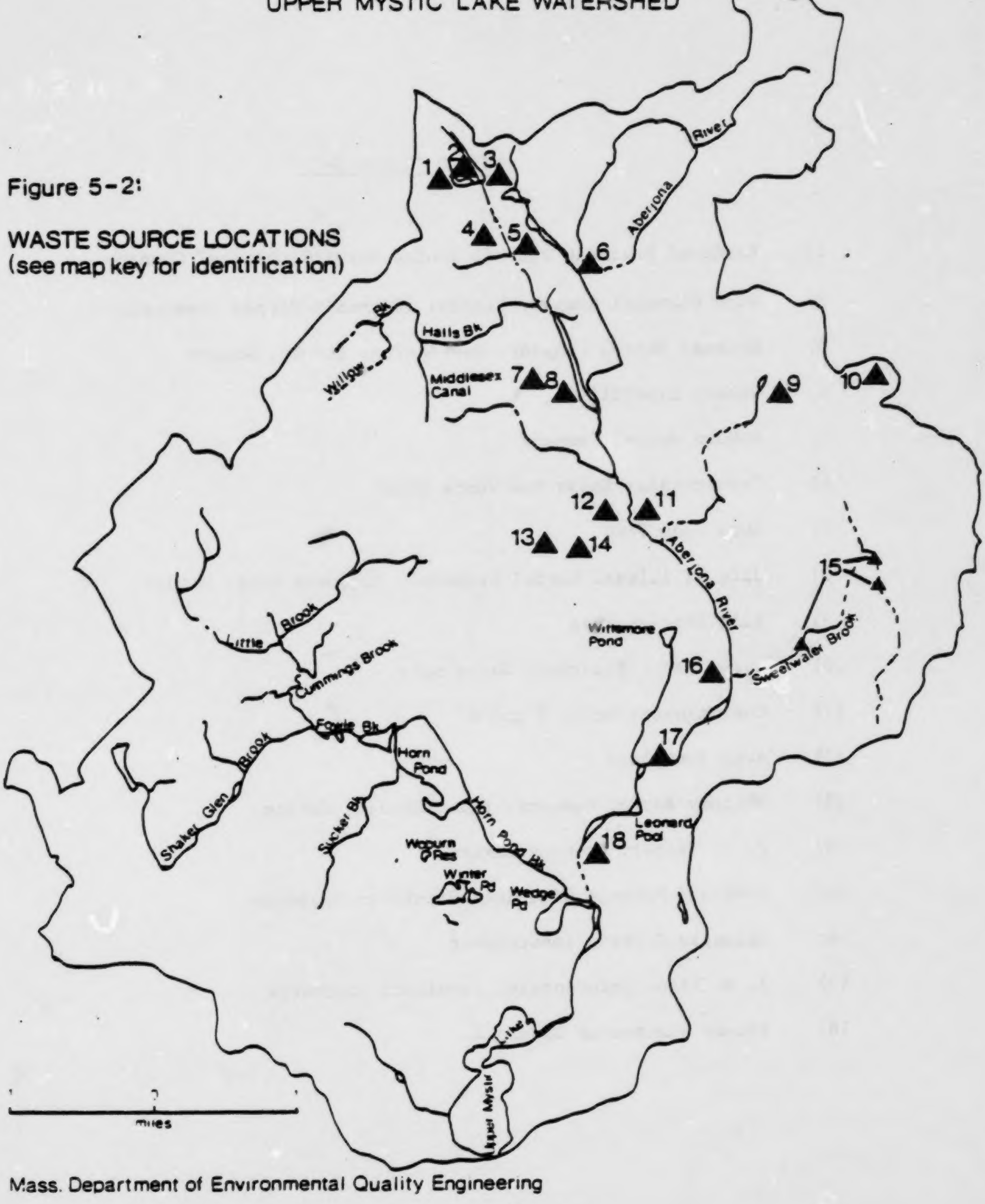
In order to regulate and financially assist in clean-up or containment of such sites, the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 was passed. Under the provisions of that law Stauffer Chemical Company is presently conducting a detailed study of the site and is committed to its share of the clean-up. The investigation includes an assessment of the location, composition and quanity of waste deposits on the site and their impact on ground and surface waters, and will propose remedial actions. The study should be completed in 1983.

Development of the site was eventually discontinued when the magnitude of the problem was recognized and in June of 1981 a perimeter fence was installed to prevent access to the site. The site is of concern with regard to surface water contamination because the Aberjona flows through the site and groundwater is a major source of the baseflow. Halls Brook storage area is also in close proximity of the site. A detailed investigation of the impact of the site on surface waters was beyond the scope of this urban runoff study and is included in the Stauffer study. The data collected at the Mishawum Road sampling station (IS1) which is on the Aberjona below the site, does, however, isolate the contributions of the upper watershed (Figure 3-11) as discussed in Chapter 6.0.

UPPER MYSTIC LAKE WATERSHED

Figure 5-2:

WASTE SOURCE LOCATIONS
(see map key for identification)


1
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11
12
13
14
15
16
17
18
Aberjona River
Halls Bk
Willow Bk
Middlesex Canal
Little Brook
Cummings Brook
Fowle Bk
Horn Pond
Horn Pond Bk
Shaker Glen Brook
Sucker Bk
Woburn Res
Winter Pd
Wedge Pd
Whittemore Pond
Sweetwater Brook
Leonard Pool
Upper Mystic Lake
miles

Mass. Department of Environmental Quality Engineering

KEY TO FIGURE 5-2

1) Railroad Drainage Ditches behind Harwick Chemical Company

2) Olin Chemical Company Lagoons (formerly Stepan Chemical)

3) Whitney Barrel Company, New Boston, Street, Woburn

4) Woburn Landfill

5) Woburn Barrel Company

6) Industriplex Hazardous Waste Site

7) Auto Junk Yard

8) Site of illegal barrel disposal, Mishawum Road, Woburn

9) Salt Storage Area

10) Incom Inc., Hazardous Waste Site

11) Contaminated Wells G and H

12) Auto Junk Yard

13) Whitney Barrel Company, Salem Street, Woburn

14) J. J. Tannery Company Lagoon

15) Combined Manhole Discharge Points in Stoneham

16) Atlantic Gelatin Impoundment

17) J. H. Winn, Incorporated permitted discharge

18) Former Winchester Landfill

Table 5-9: HISTORY OF LAND USE AT THE INDUSTRIPLEX SITE

Date	
1853	Chemical Works established - supplied chemicals to the textile, leather and paper industries.
1863	Merrimac Chemical Company bought out Chemical Works - grew into one of the largest chemical manufacturers in the country - produced arsenical compounds for insect control.
1917	New England Manufacturing Company was established by Merrimac Chemical - produced TNT and explosives during WW I.
1929	Monsanto Company purchased Merrimac Chemical.
1931	Monsanto closed the chemical plant.
1934	New England Chemical purchased the land and began to produce hide and bone glue.
1936	Glue factory purchased by Consolidated Chemical Industries, Inc.
1963	Glue factory purchased by Stauffer Chemical Company who continued to produce animal glue and grease.
1968	Property acquired by William D'Annolfo - subdivided for development.

Source: Tufts University, Department of Urban and Environmental Policy, 1980.

Other sites in the Watershed are under investigation by the DEQE Division of Hazardous Waste to determine if problems exist. Table 5-10 lists the areas which are currently of concern, the types of contamination being investigated, the status of that investigation, and any actions which have been taken. The Stepan Chemical Company site listed there is discussed in more detail in the next section.

All of these sites, except for Incom, Inc. in Reading, are in close proximity to surface waters. If the contaminants are able to reach these waterways they may be easily transported to other areas of the Watershed. Although runoff may help to move pollutants from these sites to nearby rivers and streams, these hazardous substances are not typically associated with urban runoff pollutant loads. They should therefore be considered a separate source of pollution.

The contaminants present at more than half of these sites are still being identified; thus their impacts on the Watershed cannot be determined yet. At those areas where the types of hazardous material present have been determined, some form of action has been taken to confine or clean-up the contamination.

Another contributor of non-point source pollution is the Woburn landfill. Leachate from this area enters the brook which borders its southern end. Previous reports have indicated that the high iron concentrations present in the Hall's Brook area were attributed to the landfill (Mass. WRC, 1975). Recent data collected in this area support this theory.

Although the concentration of iron in the brook south of the landfill shows evidence of some iron contamination, this is not the only area with this problem. Slightly upstream of the landfill, iron was also found in the drainage network along the B & M Railroad. Concentrations of up to 185 mg/l iron, substantially greater than those observed near the landfill, were detected. Table 5-11 shows the variations in iron levels along the drainage ditch from north of the landfill down to the tributary into which landfill leachate drains.

Groundwater testing within and outside of the leaching field indicated that the landfill may be contributing approximately 2 mg/l iron. The well affected by the leachate showed concentrations of 4.2 mg/l in comparison to the background level of approximately 2.2 - 2.5 mg/l (Moore, 1982). It is evident that the landfill is a contributor to the load of iron in this area but that there is also an additional source which has not been identified.

Point Sources

In an effort to quantify and control the wastes being discharged from point sources, the National Pollutant Discharge Elimination System (NPDES) was established under Section 402 of the Federal Clean Water Act. To legally dispose of pollutants in navigable waters, the discharger must obtain an NPDES permit from EPA or an authorized state agency. These permits outline effluent limitations and monitoring requirements which the discharger must comply with.

Applications for 16 permits have been received for point discharges in the Upper Mystic Lake Watershed since the start of the program (see Table 5-12).

Table 5-10 POTENTIAL AND CONFIRMED HAZARDOUS WASTE SITES IN THE UPPER MYSTIC LAKE BASIN

Site	Type of Contamination	Status	Action Taken
Atlantic Gelatin Hill Street, Woburn	Inactive industrial sludge landfill	Site under investigation to determine if hazardous waste is present	None
Incom Inc. 312 Ash Street Reading	Improper disposal of polyurethane waste, approximately 600 drums	Confirmed hazardous waste site-site under investigation to ensure clean-up is complete	Drums removed 3/23/81
Industriplex 128 Commerce Way, Woburn	Abandoned waste pits containing primarily arsenic, lead and chromium	Confirmed hazardous waste site-active investigations underway	Site secured with fence, 6/81
J.J. Tannery Co. Salem St., Woburn	Industrial sludge disposal, unlined industrial waste lagoon	Confirmed hazardous waste site-site under investigation	None
Mishawum Road Woburn	Abandoned barrels of waste toluene diisocyanate, and polyurethane resin	Confirmed hazardous waste site-site secured-remedial action has been completed	Barrels removed
Stepan Chemical Co.	Industrial waste impoundments	Site under investigation to determine if hazardous waste is present	None
Whitney Barrel Co. New Boston Street Woburn	Chemical disposal, barrel washing	Confirmed hazardous waste site-site under investigation	None
Whitney Barrel Co.	Chemical spills, barrel washing	Confirmed hazardous waste site-site under investigation	Clean up ordered
Woburn Barrel Co. New Boston Street Woburn	Barrel washing	Site under investigation to determine if hazardous waste is present	None

Sources: Massachusetts Department of Environmental Quality Engineering, 1981a.

Table 5-11: **IRON CONTENT OF SURFACE WATERS NEAR WOBURN LANDFILL**

Iron Concentrations (mg/l)

Date	(1) Ditch Above Olin Chemical	(2) Ditch at Olin Chemical	(3) Ditch South of Resin and Pigment Co.	(4) Tributary to Ditch South of Station 3	(5) Tributary South of Landfill
12/12/79*	8.5	5.2	9.0	1.5	5.1
10/28/80*	70.0	1.0	4.2	1.8	5.5
2/26/81*	2.0	1.6	1.9	0.40	3.4
7/29/81*	4.0	185.0	6.0	----	4.0
11/81**	----	----	----	----	5.8

Sources: * Massachusetts Department of Environmental Quality Engineering, 1982d.
** Moore, 1982.

Table 5-12: APPLICATIONS RECEIVED FOR NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM PERMITS

Discharge	Community	Federal Permit Number	Mass. Permit Number	Date Issued	Date Expired	Receiving Location
Raytheon Co. Spencer Lab	Burlington	MA0001431		4/21/75	1/1/76	Terminated
RCA Corp.-Aerospace Systems Division	Burlington	MA0001546				Deer Island STP
Montvale Enterprises	Stoneham	MA0020443				Deer Island STP
Sanborn Trucking Co.	Stoneham	MA0023671				Deer Island STP
Stoneham DPW	Stoneham	MA0102059	M-147	6/12/75	4/1/76	Deer Island STP
Compugraphic Corp.	Wilmington	MA0024171				Wilmington WTF
Stepan Chemical Co.	Wilmington	MA0005304	M-441			Special Problem
Swift Edible Oil Co.	Winchester	MA0020923				Deer Island STP
J.H. Winn, Inc.	Winchester	MA0001279	M-35	6/29/73	6/29/78	Aberjona River
A-1 Precious Metal Plating, Inc.	Woburn	MA0024490				Deer Island STP
Atlantic Gelatin	Woburn	MA0020401				Deer Island STP
Joseph P. Mahoney Co.	Woburn	MA0024139				Deer Island STP
Lipton Pet Foods, Inc.	Woburn	MA0023124				Deer Island STP
Systems Printed Circuit Corp.	Woburn	MA0021601	M-432	4/21/75	1/1/76	Terminated
Woburn	Woburn	MA0102008		10/31/75	6/7/77	Deer Island STP
Woburn Dump	Woburn	MA0023591				Woburn SD

Source: U. S. EPA, 1981.

Of these applications, only five permits were issued. All five issued permits have passed their expiration date; however, two have been terminated and two have connected to the MDC system since their time of application. The remaining permitted discharge consists of cooling water from J.H. Winn, Inc. in Winchester. This discharge is felt to be beneficial to the Aberjona River because the discharge water which originates from wells helps to diminish the low flow problems (MAPC, 1977a). This is probably why EPA has not taken action against J.H. Winn, Inc. for being negligent about renewing their permit. Ten of the remaining 11 dischargers are connected to the MDC Sewer System which transports their wastes to the Deer Island Treatment Plant, eliminating the need for NPDES permits.

The final NPDES applicant was Stepan Chemical Company. No permit was issued for their discharge which was labelled by EPA as being a "special problem" due to their waste disposal practices at the site. High concentrations of ammonia, sulfate, chlorides, and dissolved solids have been detected in the drainage ditches which surround the plant now owned by Olin Chemical Company. Data on the ditches at the eastern border of the Olin site, collected under this study, support these findings (see Table 5-13). Contaminated groundwater is discharging to these ditches and then flows down to Hall Brook and the Aberjona River.

From sometime prior to 1965 until July 1971, wastes were discharged into unlined "acid pits" on the site. These wastes were untreated and contained contaminants such as those just mentioned. For the next year the wastes were treated before being discharged into the pits. In 1972, these pits were replaced with two polyvinyl chloride lined lagoons into which sulfate bearing wastes treated with a calcium hydroxide slurry were discharged (Mass. DEQE, 1982a).

The effectiveness of the liners was lost when punctures occured, possibly due to improper lagoon design, caustic properties of the waste being discharged, or sludge removal practices (Geotechnical Engineers, Inc., 1978). This problem and the prior use of the unlined "acid pits" are believed to be the primary sources of the contaminants found in the groundwater. A study recently conducted for Olin Chemical showed that the ammonia plume in the groundwater is highest in the vicinity of the lagoons, with a secondary plume located near some storage tanks on their property. In this area, the source is believed to be faults in the sewer line (Malcolm Pirnie, Inc. 1982).

DEQE is currently working with Olin Chemical on remedying the situation. During the summer of 1981 the liner in one lagoon was replaced with a thicker barrier designed with more safety features. The second liner should be replaced sometime within the next year. In addition, a closer examination of the sewer line will be conducted so that appropriate repairs can be made (Dore, 1982). If these problems are solved and no further sources of contamination are detected, the quality of the ground and surface waters in this area should improve considerably over time. There are currently no plans for groundwater treatment.

Additional point source problems in the Watershed can be attributed to

TABLE 5-13: WILMINGTON INDUSTRIAL DRAINAGE NETWORK DATA (mg/l)

Date	8/5/81			8/15/81		8/19/81	9/2/81
Station*	1	2	3	2	3	2	2
pH				5.7	7.4	5.3	5.3
BOD					2.4	3.0	1.5
COD	281	58	291	41	171	67	48
TS				258	1414	252	318
SS						5.0	1.0
TVS							64
VSS						4.0	0.5
TKN	323	52	300			30	34
NH_3-N	310	29	292	26	230	30	29
NO_3-N	1.4	0.2	3.0	0.5	0.8	0.2	0.1
NO_2-N						0.004	0.004
TP	0.23	0.02	1.2	3.2		0.5	0.03
PO_4-P						0.03	0.03
Sulfate	1225	135	1025	135	850	173	137
Al	150	0.48	4.9	0.10	0.10	0.23	0.10
As	0.13	0.01	0.03	0.02	0.06	0.01	0.01
Cd	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01
Cr	<0.02	<0.00	<0.02			<0.02	<0.02
Cu	0.04	<0.01	<0.01	<0.01	0.01	0.01	<0.01
Fe	1.2	3.0	3.1	1.7	0.40	0.91	<0.02
Pb	0.06	<0.03	0.03	<0.03	<0.03	<0.03	<0.03
Mn	1.8	1.3	3.0	1.2	2.4	1.2	0.2
Ni	0.03	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Sn	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Zn	0.09	<0.01	<0.01	0.01	0.01	0.01	<0.01

* See Figure 3-7 for locations of sampling stations

surcharging sewers, particularly in the Towns of Stoneham and Winchester. Nineteen combined manholes located in three areas of Stoneham cause sewer overflows into Sweetwater Brook. At these points, the stormwater and sewer lines are separate yet open to each other (see Figure 5-3). If a blockage occurs in either line or if their capacities are exceeded, the sewage and stormwater may mix. Sewage laden stormwater then travels to Sweetwater Brook where it is discharged.

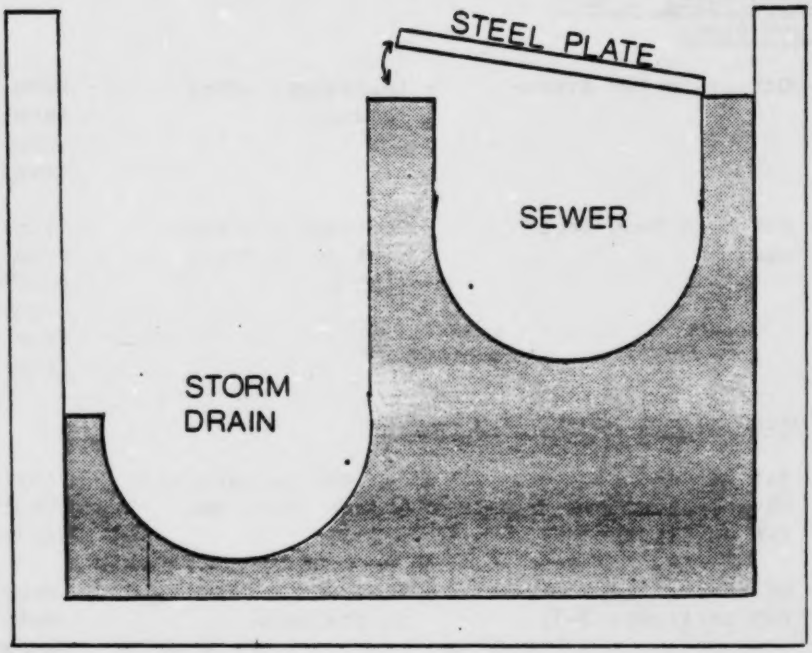
This problem was brought to the attention of the Construction Grants Section of DWPC, and funds were obtained to conduct the initial investigation and design studies. Although the study of the combined manholes has been completed, funding for the alterations necessary is being delayed. Funding for the Stoneham sewer line studies included an investigation of the town's pumping station which does not have the capacity to adequately handle current flows. This study has not been completed at this time; and the funding for the manhole repairs is tied to completion of this investigation.

Winchester completed an infiltration/inflow study in 1978 which identified a number of problems in the sewer system, ten of which potentially surcharged to the Lake or its tributaries. Additional work has been completed since that time to further investigate those problems and evaluate corrective measures. The recently completed facilities plan presents the results of that investigation reducing the number of problem areas from ten to six (Coffin & Richardson, 1982). Table 5-14 lists the six problem areas and recommended remedial actions. Winchester has developed a ten year strategy using town funds to make the needed changes and repairs in the sewer system. If funding is available from DEQE's Construction Grants Program the work could be completed sooner.

Limited data was collected in two of these problem areas during the study. A periodic overflow occurs from the Cambridge street sewer at a manhole just south of Everett Avenue. The sewage runs into a nearby stormwater catchbasin and into the Lake (outfall W5 on Figure 3-3). Data from three grab samples collected is shown on Table 5-15. August 19th and September 17th samples were taken shortly after storm events. September 2nd was a dry weather day and elevated levels may be due to residual sewage being washed out of the manhole sump by groundwater infiltration.

Elevated bacteria and nutrient levels, and blue-tinted water were detected at the Boat Club Inlet on several occasions (discussed in Section 6.7). Upstream of the Everett Avenue sampling station is the point of discharge for a section of Winchester's stormwater drainage system at Glen Road believed to be a possible source of this contamination. To investigate this, bacteria samples were collected at four points within the stormwater system during dry weather (see Figure 3-4). The results of this survey, shown on Table 5-16, indicate the presence of coliform bacteria at several points in the line. The Wildwood Road/Albamont Street site is one of the identified problem areas in Winchester. These results, however, do not fully explain bacteria levels at the inlet since the Glen Road site, which is the stormwater discharge point to the inlet, had lower levels than the inlet itself. Further investigation of this problem is needed.

Figure 5-3: TYPICAL COMBINED MANHOLE


STEEL PLATE
SEWER
STORM
DRAIN

Source: CDM.Draft.

Table 5-14: AREAS WITH SURCHARGING SEWER PROBLEMS IN WINCHESTER

Area	Reason	Recommendation
Surcharging to the Boat Club Inlet		
- At intersection of Wildwood and Albmont Streets	- Inadequate sewer capacity on Cambridge Street	- Relief sewer on Wildwood to Wedgemere Avenue
Surcharging to Horn Pond Brook		
- Off Sylvester Avenue	- Inadequate sewer capacity	- Remove part of service area from this collection sewer (see below)
- Off Horn Pond Brook Road	- Sediment accumulation in inverted siphon	- Eliminate siphon with new connection to MDC sewer and remove this area from downstream collection sewer(as above)
Surcharging to Upper Mystic Lake		
- Between the two forebays of the lake (W6 on Figure 3-3)	- Inadequate capacity in the sewer and siphon	- Construct a relief sewer and new siphon inlet structure
- Off Cambridge Street (W5 on Figure 3-3)	- Inadequate capacity in the sewer	- Construct relief sewers. Eliminate excessive I/I
Surcharging to Shaker Glen Brook		
- Off Thornberry Road	- Wet weather flow exceeds pumping capacity	- Overhaul pumps and piping to increase pumping capacity. Eliminate excessive I/I

Source: Coffin & Richardson, 1982.

Table 5-15: CAMBRIDGE STREET END-OF-PIPE DATA

Parameter		DATE	
	8/19/81	9/2/81	9/17/81
pH	7.2	7.3	7.8
COD (mg/l)	25	7.9	28
BOD (mg/l)	1.8	0.6	3.6
TS (mg/l)	166	194	142
SS (mg/l)	0.5	0.5	3.0
VSS (mg/l)	0.0	0.5	1.0
Sulfate (mg/l)	16	17	
TKN (mg/l)	0.34	0.31	7.5
NH_3-N (mg/l)	0.03	0.01	1.3
NO_3-N (mg/l)	1.3	1.1	1.3
NO_2-N (mg/l)	0.002	0.001	0.047
TP (mg/l)	0.08	0.05	0.47
PO_4-P (mg/l)	0.06	0.05	0.42
Total Coliform (MPN/100ml)	25,000	25,000	13,000
Fecal Coliform (MPN/100ml)	5,300	3,000	700
Arsenic (mg/l)			0.01
Copper (mg/l)			0.01
Iron (mg/l)			0.12
Manganese (mg/l)			0.03
Zinc (mg/l)			0.02

Additional sewer problems have been identified within the MDC system and excessive infiltration/inflow in Woburn is one suspected cause of these overlows. An infiltration/inflow study should be conducted in Woburn so that plans to alleviate these problems can be developed. High bacteria counts were also recorded at the outlet of the Lake during the sampling program. This problem needs further investigation including additional sampling in the southern part of the Lake and of the stormwater outfalls along the Arlington shoreline.

Another stormwater outfall to the Lake was sampled after the presence of an orange discharge was reported by a nearby resident (outfall W7 on Figure 3-3). This discharge located off Niles lane in Winchester, had an iron concentration of 294 mg/l which would explain the orange precipitate. The aluminum level was also high at 1.4 mg/l; the pH was 6.5. Further investigation is needed to determine the severity and source of this problem.

There are probably numerous other point and non-point sources of pollution in the Upper Mystic Lake Watershed which have not been detected yet; however, knowledge of the sources discussed in this chapter has helped to explain some of the water quality traits observed. The impacts attributed to these sources of pollution are discussed in Chapter 6.0.

Table 5-16: WINCHESTER STORMWATER LINE COLIFORM DATA - August 31, 1981
(Colonies/100 ml)

Station (see Figure 3-4)	Total Coliform	Fecal Coliform
Boat Club Inlet	26,000	3,800
Glen Green/Glen Road (d)	12,000	1,800
Church Street (c)	23,000	3,000
Wildwood Road (b)	1,200	280
Wildwood Road/Albamont Street (a)	400,000	3,500

6.0 WATER QUALITY CONDITIONS & IMPACTS

One of the objectives of this project was to determine the impact of the various sources of pollution described in Chapter 5.0 on the Aberjona River and Upper Mystic Lake. The water quality conditions found during the sampling program and the contributing sources of pollution are discussed in detail in this chapter. Additionally, to provide a basis for explaining the conditions found, the characteristics and significance of the various pollutants are described. The relationship between existing and historical conditions is also considered. All of the raw data collected is included in Appendix A.

The pollutant loads to the Upper Mystic Lake presented in this chapter are divided into several components: baseflow and urban runoff for the Aberjona River, Boat Club Inlet, West Shore Inlet, and direct drainage to the Lake, respectively; and the Sweetwater Brook sanitary contribution. Based on the data collected, loads from more specific sources could not be calculated but were included in the field measurements and are consequently included in the baseflow or urban runoff loads. Again, baseflow loads were calculated based on dry weather quality measurements, and urban runoff on wet weather. Specifically:

- Aberjona baseflow includes the influence of Sweetwater Brook sanitary overflows during dry weather, and groundwater contamination from upstream industrial areas;
- Aberjona baseflow and urban runoff reflect the contribution of the sewer problems along Horn Pond Brook in Winchester, as discussed in Chapter 5.0, to the extent they were occurring during the sampling program; and
- Loads from the Boat Club Inlet include the elevated nutrient and bacteria levels found during both wet and dry weather sampling, though the specific source of this contamination is not known.

6d

Additionally loads attributable to sewer overflows to storm drains with Lake outfalls were not calculated. These sources will be discussed in the appropriate sections.

6.1 TEMPERATURE

Thermal Properties and Controlling Conditions

River Systems. Rivers generally have homogeneous vertical temperature profiles due to the mixing action of turbulent flow. Horizontal differences do occur under certain conditions due to the effects of shading or varying flow conditions. River temperatures tend to vary more rapidly than those of lakes and are controlled by air temperature and characteristics and location of the river's source. For example, for a system with a single source in the headwaters, temperature equilibrates with air temperature as it moves downstream. On the other hand, if the river receives groundwater along its length, it will have a fairly constant temperature. During cold weather, ice may form if the entire system reaches 0°C. Additionally, inputs from tributaries and waste sources, and other effects such as shading in culverts, can significantly change temperature.

Lake Stratification. Most deep lakes in temperate regions, such as Upper Mystic Lake, undergo thermal stratification. In the spring and continuing through the summer, solar radiation heats the upper waters of a lake more than the lower waters. The density of the warmer surface water is then less than that of the cooler deeper waters, and the warm water forms a separate layer which "floats" on the cold water preventing vertical mixing. This upper layer which is generally circulating and fairly turbulent is called the epilimnion. The deep, cold relatively undisturbed layer is called the hypolimnion. Between the epilimnion and hypolimnion, there is a transition layer where the temperature gradient is steep. This transition region is called the metalimnion and the maximum temperature gradient the thermocline.

Figure 6-1 shows typical seasonal stratification patterns. Line A shows a mid-summer temperature-depth profile with thermal stratification firmly established. During autumn, the surface waters begin to cool, dropping the thermal gradient deeper into the water column as shown by Line B. As the surface water temperature approaches the temperature of the bottom waters, the layers begin to mix. Autumn storms often can increase mixing by wind turbulence. Eventually by late autumn, the water column is one uniform temperature and the lake completely mixes, Line C. This complete mixing is called fall turnover and results in a homogeneous vertical temperature profile.

During winter, if no ice forms, the lake remains completely mixed. If ice forms, the lake can stratify with an inverse temperature difference. (Ice and water (0-1°C) float on warmer bottom waters (3-5°C).) As spring approaches, the ice melts and surface waters start to warm up; thus the water column becomes a uniform temperature again, allowing complete circulation. This is called spring turnover. A lake that has both a spring and fall turnover is classified as dimictic.

Water Quality Significance

Temperature is important because it is a controlling factor in the stability, chemistry and biology of aquatic systems. In particular, these include:

- water movements and circulation;
- stratification;
- photosynthesis;
- dissolved oxygen solubility;
- chemical equilibria such as for carbonate and ammonia;
- aquatic life (metabolism, behavior, toxicity); and
- aesthetics.

The Massachusetts Class B Water Quality Standards require that the temperature not exceed 83°F (28.3°C) for warm water fisheries or 68°F (20°C) for cold water fisheries. More specific tolerance levels for several fish species found in the Upper Mystic Lake are shown in Table 6-1.

Existing Conditions - In-stream

In-stream temperatures recorded during the sampling program are shown in Table 6-2. No consistent trends are seen moving downstream on the Aberjona from Mishawum Road to the USGS gauging station. Temperature differences along the Aberjona ranged from 0 to 6°C on any given day. The Boat Club and West Shore Inlets were generally cooler than the Aberjona probably due to a shorter period of air exposure and shading influences. All the values were well below the 28.3°C Class B standard for warm water fisheries indicating that temperature is not a problem along the Aberjona and Inlets.

The wet weather values shown are averages of up to five measurements taken during the 24 hour sampling period. The discrete measurements were also analyzed for trends. The only noticeable trend was an initial decrease and subsequent increase of as much as 3.5°C at all stations during the course of the June 22, 1981 storm. That storm was the most severe event sampled and also showed extremes in other parameters as discussed in the appropriate section.

Existing Conditions - Upper Mystic Lake

The Lake can be classified as a dimictic, temperate lake, typical of other deep New England lakes. During the summer, the main basin establishes a firm thermal stratification. It begins in early May and continues until fall turnover in late November or early December. The two forebays are too shallow to develop a strong stratification. During winter, ice cover is often incomplete and during moderate winters probably does not occur at all (Mass. DEQE, 1975). A discussion of thermal stratification including seasonal temperature profiles can be found in the Dissolved Oxygen section (6.2). However, there were several additional thermal influences that were observed during this project that are worth mentioning briefly.

Figure 6-1: SEASONAL STRATIFICATION PATTERNS

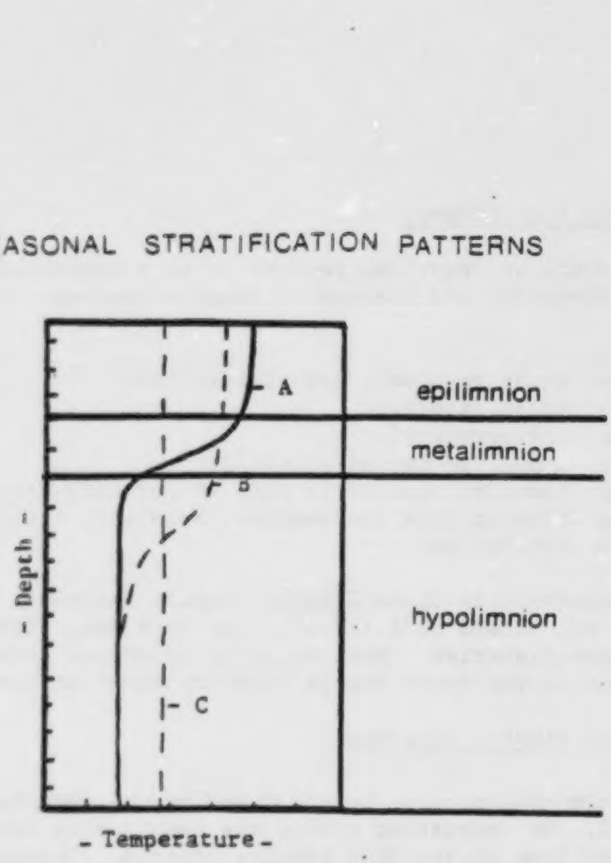

A
epilimnion
metalimnion
B
hypolimnion
C
- Depth -
- Temperature -

Table 6-1: TEMPERATURE TOLERANCE LEVELS FOR SELECTED FISH

Species	Median Tolerance Level (°C)
Large Mouth Bass	36.4
Carp	35.7
Brown Bullhead	35.1
Golden Shiner	34.7
Yellow Perch	31.0
White Sucker	30.2

Source: McKee & Wolf, 1963.

Table 6-2: RECORDED INSTREAM TEMPERATURES AND DISSOLVED OXYGEN CONCENTRATIONS

	Dry Weather Conditions				Wet Weather Conditions							
	5-20-81 Temp(°C)	8-5-81 Temp(°C)	8-19-81 Temp(°C)	9-2-81 Temp(°C)	6-22-81 Temp(°C)	6-22-81 D.O.(mg/l)	7-13-81 Temp(°C)	7-13-81 D.O.(mg/l)	8-5-81 Temp(°C)	8-5-81 D.O.(mg/l)	8-25-81 Temp(°C)	8-25-81 D.O.(mg/l)
Mishawum Road	13.5	24.0	23.0	18.0	21.6	6.5	22.5	7.1	23.0	8.0		
Mill Street	13.0	23.0	19.5	18.0	22.4	4.6	22.0	6.2	22.0	6.1	18.5	6.8
Washington Street	14.0	23.0	17.0	18.0	22.0	5.7	21.2	7.2	21.7	7.8	18.5	7.4
USGS	10.5	23.0	17.0	18.0	22.9	5.9	22.2	6.2	22.6	7.2	19.3	10.0
Sweetwater Brook	15.0	23.0	20.0	18.0	19.6	6.5	19.0	6.7	20.8	8.3	17.0	6.1
Boat Club Inlet	10.0	17.0	17.0	16.0							17.1	8.8
West Shore Inlet	12.9	17.0	14.0	16.0								

As described in detail in the Dissolved Oxygen section, the thermocline in the main basin dropped slightly in the water column, as much as one meter, in response to wet weather conditions. This drop occurred because storm-related wind and rain cooled the epilimnion. This cooling eroded away the thermal gradient in the metalimnion. This process is often called metalimnetic erosion.

A second thermal characteristic was observed in the early summer temperature profiles. The main basin revealed a slight increase in temperature of 1-3°C above the sediments. According to Hutchinson (1957) this could be the result of a density current. During the early summer, the water in contact with the sediment at intermediate depths (30 to 50 feet) tends to lose heat rather than gain heat from the sediments. The result is an increase in the density of this water. The movement of dissolved materials into the water, causes it to flow down the slope of the basin. Since its increased density is due in part to solutes from the sediments as well as loss of heat, it will stabilize at a depth at which the water above it is slightly cooler than itself.

In terms of temperature related impacts on aquatic life, one concern is the ability of the Lake to support a cold water fishery. During the mid-summer, only the lower metalimnetic and hypolimnetic waters were cold enough to support a cold water fishery. As discussed in the next section, however, they did not contain the oxygen required. Surface water and forebay temperatures did not exceed the warm water standard of 28.3°C or the requirements listed in Table 6-1 for warm water fish. Following a hot period in July 1981, both forebay and main basin surface temperatures did, however, come close (28°C) to the standard.

Comparison with Historic Conditions

Average monthly temperatures along the Aberjona River appear to fluctuate by 2 to 4°C based on historic data. No trends are obvious from year to year, however. The variations are probably due to corresponding differences in air temperature and sampling technique. Historic temperature ranges for the Lake from 1974 to 1978 were well within the range of current temperature values.

6.2 DISSOLVED OXYGEN AND BIOCHEMICAL OXYGEN DEMAND

Distribution and Controlling Conditions

Dissolved oxygen (D.O.) is the uncombined free oxygen available in water. The solubility of D.O. is primarily regulated by temperature with solubility increasing with colder temperatures. Turbulence, salinity and organic matter content also affect solubility. Gaseous oxygen enters aquatic systems through absorption at the air-water interface, and as a product of photosynthesis. Conversely, oxygen is consumed by animal, plant and bacterial respiration, and chemical oxidation. The difference between theoretical saturation and measured dissolved oxygen is called the actual oxygen deficit, and the amount of oxygen consumed over a period of time the relative deficit. The latter is most applicable to lake systems as discussed below. Plant photosynthesis which produces oxygen and respiration which consumes oxygen may cause significant diurnal fluctuations. Of particular concern in this study are seasonal fluctuations in lake systems.

Seasonal Fluctuations. In surface waters, seasonal fluctuations are highly correlated to temperature and, consequently, solubility changes as influenced by the oxygen demands of the system.

In deep lake systems, once the lake thermally stratifies in the spring virtually no dissolved oxygen enters the hypolimnion. Consequently, there is a finite amount of dissolved oxygen in the bottom waters of the lake. This limited dissolved oxygen is used up over the period of stratification in the biochemical breakdown of organic matter in the water column and at the sediment-water interface, and similarly by chemical oxidation. Thus, the rate and extent of oxygen depletion is controlled by the amount of oxidizable organic matter received during stratification and of chemical substances which will be oxidized. These oxygen demanding materials can come from both external sources in the drainage area and internal sources or that actually produced within the lake. The relative contribution of these two sources is extremely important when considering controls on the dissolved oxygen regime.

Biochemical Oxygen Demand. Biochemical oxygen demand (BOD) is a measure of the amount of oxygen required by bacteria when oxidizing carbonaceous organic matter under aerobic conditions. As oxidation proceeds the amount of organic matter present decreases and consequently so does the BOD. This is a natural purification process which depends to a large extent on the amount of oxygen available. Thus, this process is much more effective in fast moving streams where oxygen is constantly being introduced from the atmosphere than in more quiescent water bodies.

The BOD test is basically a bioassay procedure where the amount of oxygen consumed by bacteria in the breakdown of organic matter in the sample is measured. The time required for complete oxidation is dependent on the organic

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matter, the organisms present, and environmental conditions such as temperature. It is generally assumed, however, that the reaction is complete within 20 days. However, since such an extended test period is not always practical and it has been demonstrated that a large part of the demand is generally exerted within five days, BOD is often measured as that five day demand, BOD_5.

The BOD test has historically been used as an indicator of the strength of a particular waste or degree of pollution of a water body. BOD_5 values of 3.0 mg/l or less generally indicate unpolluted waters, while secondary wastewater effluent is generally around 30 mg/l and urban runoff around 20 mg/l (Thomann, 1972).

The biochemical demand discussed above is that required to oxidize the carbonaceous matter present. There is a second component of the demand, nitrogenous oxygen demand (NBOD). NBOD is the amount of oxygen required to oxidize ammonia to nitrite and nitrate as discussed in Section 6.4. The NBOD test is also time consuming and was not measured in this study. NBOD can, however, be calculated using the following stoichiometric relationships:

$$2NH_3 + 3O_2 \longrightarrow 2NH_2^- + 2H^+ + 2H_2O$$

$$2NO_2^- + O_2 + 2H^+ \longrightarrow 2NO_3^- + 2H^+.$$

Water Quality Significance

The relationship of D.O. to the physical and chemical characteristics of a lake plus its importance to biological organisms make it an excellent indicator of water quality conditions.

While fish vary in their oxygen requirements according to species, age, activity, temperature, and nutritional state, standards have been established for the maintenance of a "well-rounded" warm and cold water fishery, respectively. Massachusetts Water Quality Standards for Class B waters require D.O. to be a minimum of 5.0 mg/l in warm water fisheries (83°F/28.3°C) and a minimum of 6.0 mg/l in cold water fisheries (68°F/20°C). Decreased D.O. levels, if sufficiently severe, can also adversely affect aquatic insects and other animals upon which fish feed (U.S. EPA, 1976).

A lack of D.O. in the water column causes anaerobic decomposition of any organic materials present. Such decomposition tends to cause the formation of noxious gases such as hydrogen sulfide, carbon dioxide and methane. Under anoxic conditions, metals and phosphorus are released from the sediments and can accumulate to concentrations of concern.

Existing Conditions - In-Stream

Table 6-2 includes in-stream D.O. data collected during the course of the project. In-stream D.O.s were not expected to be a problem under the flow conditions sampled, so limited data were collected. Values ranged from 4.6 to 10.0 mg/l with only one out the twenty measurements below the 5.0 mg/l standard for warm water fisheries.

In-stream BOD_5 data are summarized in Table 6-3. The highest BOD_5 levels were found in Sweetwater Brook where combined manhole overflows elevated the concentrations. The values reflected intermittent sewage contamination showing ranges of 5.1 to 100 mg/l and 2.2 to 189 mg/l for dry and wet weather, respectively. The median value for wet weather was lower than the dry weather concentration, indicating that stormwater may be diluting the BOD level.

Median concentrations along the Aberjona ranged from 2.4 to 8.7 mg/l with the concentration ranges being fairly wide. In general, wet weather concentrations were consistently higher than dry as reflected by the medians listed. A spatial trend is evident moving downstream along the Aberjona as BOD_5 levels decreased from Mishawum Road to Mill Street, increased at Washington Street due to the input from Sweetwater Brook upstream, and decreased again from Washington Street to the USGS gauge. While the majority of the samples were well above the 3 mg/l for unpolluted waters, the dry weather USGS concentrations ranged from 2.4 to 3.3 mg/l.

The median BOD concentrations for the Boat Club and West Shore Inlets were elevated during wet weather, due to urban runoff. High values at the Boat Club Inlet, up to 27 mg/l, corresponded to high phosphorus and bacteria indicating sewage contamination as discussed in Section 5.2. Dry weather medians were well below the polluted level.

External Loads to Upper Mystic Lake. The annual loads of BOD_5 entering the Upper Mystic Lake are shown on Table 6-4. The largest source of BOD is from urban runoff in the Aberjona River which contributed approximately 59 percent. Baseflow and the Sweetwater Brook sanitary contribution account for an additional 30 and 7 percent, respectively.

It should be remembered that BOD_5 represents only a portion of the total BOD. While ultimate BOD was not measured in this study, an estimated range can be calculated assuming certain oxidation rates. For oxidation rates of 0.1 and 0.25 per day, within which the actual rate should fall, the ultimate BOD values would be 349,066 lb/year and 252,516 lb/year, respectively. While these numbers are very rough they provide a general range for comparison with calculated NBOD values. NBOD was calculated, using the stoichiometric relationship discussed above and the ammonia loads from Section 6.4, as approximately 995,400 lb/year oxygen demand. From this rough comparison it is obvious that the nitrogenous oxygen demand entering the Lake is considerably higher than the carbonaceous demand.

Existing Conditions - Upper Mystic Lake

Since the forebays tend to behave differently than the main basin, they will be discussed separately. Wet weather conditions and dry weather conditions will be discussed within each section.

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TABLE 6-3 : AVERAGE INSTREAM BIOCHEMICAL OXYGEN DEMAND CONCENTRATIONS

(Based on 5 day test)

Station	BOD$_5$ (mg/l) Mean	 Median	 Range
Misnawum Road			
wet	8.9	7.4	0.4- 37.0
dry	3.7	4.2	1.2-4.5
Mill Street			
wet	6.3	5.1	1.3-19.8
dry	2.6	2.4	2.1-3.6
Washington Street			
wet	11.0	8.7	2.2-46.0
dry	9.6	4.8	1.8-33
USGS Gauge			
wet	7.3	5.7	2.9-13.0
dry	2.7	2.4	2.4-3.3
Sweetwater Brook			
wet	17.3	5.5	2.2-189
dry	38	17	5.1-100
Boat Club Inlet			
wet	9.9	6.1	0.3-27
dry	2.1	1.8	1.5-3.3
West Shore Inlet			
wet	5.9	6.4	0.9-11
dry	1.5	1.4	0.6-2.4

Table 6-4 : ANNUAL BOD LOADS TO UPPER MYSTIC LAKE

(lbs/yr)

Station	Baseflow	Urban Runoff	Sweetwater Brook Sanitary	Total
Aberjona River	70,915	140,955	15,915	227,785
West Shore Inlet	1,185	2,315	NA*	3,500
Boat Club Inlet	1,040	2,495	NA	3,535
Direct Drainage	860	1,685	NA	2,545
TOTAL	74,000	147,450	15,915	237,365

NA* = not applicable

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Forebays. Figure 6-2 shows typical dry weather mid-summer D.O. and temperature profiles measured in the forebays. The shallow depth combined with wind turbulence does not allow a stable thermal stratification to develop. Occasionally, during hot summer spells, the two forebays developed a slight temperature gradient with depth, at most, one degree centigrade per meter. However, with a moderate wind, this fragile stratification was easily disrupted. Generally, the forebays can be considered unstratified, totally mixed bodies during spring, summer and fall. Winter profiles were not taken.

As can be seen in Figure 6-2, D.O. concentrations in the forebays under dry weather conditions did not change significantly with depth, although a slight decrease in saturation was observed above the sediments due to sediment oxygen demand. Mean dry weather D.O. saturation in the surface waters of the two forebays during this study was 98%. At times, super-saturated values were found near the surface due to photosynthetic activity. Overall, the forebays maintained aerobic conditions during dry weather (mean D.O. saturation of the entire water column - 88%). In terms of impacts on aquatic life, dry weather D.O. levels were above those required to support warm and cold water fisheries. This was not the case, however, under wet weather conditions.

Figure 6-3 shows temperature and D.O. profiles observed in the forebays during wet weather conditions based on the storm response sampling runs. The solid lines represent concentrations 24 hours following the beginning of a storm, the dashed lines represent 48 hours and the dotted lines represent 72 or 96 hours (as labeled on the figure). Several important trends are demonstrated in these storm response profiles. In each of the three storms, there was a decrease in temperature in the entire water column in each forebay; a shift of as much as 2°C was observed. This temperature drop was probably due to the cooling influence of the wind and rain. With this drop in temperature, an unexpected drop in D.O. was observed. (Cooler water has a higher D.O. solubility potential). When D.O. was sampled above the sediments in the upper forebay 48 to 72 hours following the beginning of a storm, D.O. concentrations were below the 5.0 mg/l standard required to support warm water fish.

As Table 6-5 illustrates, D.O. concentrations in the upper forebay decreased considerably two meters above the sediments. For such a shallow water body, a decrease of 4.7 mg/l D.O. in one meter is indicative of extreme oxygen demanding conditions. Seventy-two hours after the beginning of the storm, D.O. levels above the sediments remained below levels required to support a healthy aquatic community. This high oxygen demand during wet weather is due to increased organic and inorganic loads entering the upper forebay from the Aberjona River. Storm related wind and wave action which allows more oxygen to enter the water column did not offset this oxygen demand. Increased turbulence may also have stirred up and exposed the organic rich forebay sediments placing an even greater oxygen demand on the water column. This sediment demand could actually be equal to or greater than that from the Aberjona River.

Main Basin. Figure 6-4 shows observed seasonal temperature and D.O. profiles in the main basin (station 4). Sampling was conducted once in December 1980, monthly from June 1981 to November 1981 and then once in May 1982. Unfortunately, monitoring was not conducted immediately following spring or fall turnover or during the 1981 winter ice cover.

Figure 6-2: DRY WEATHER TEMPERATURE & DISSOLVED OXYGEN PROFILES -FOREBAYS-

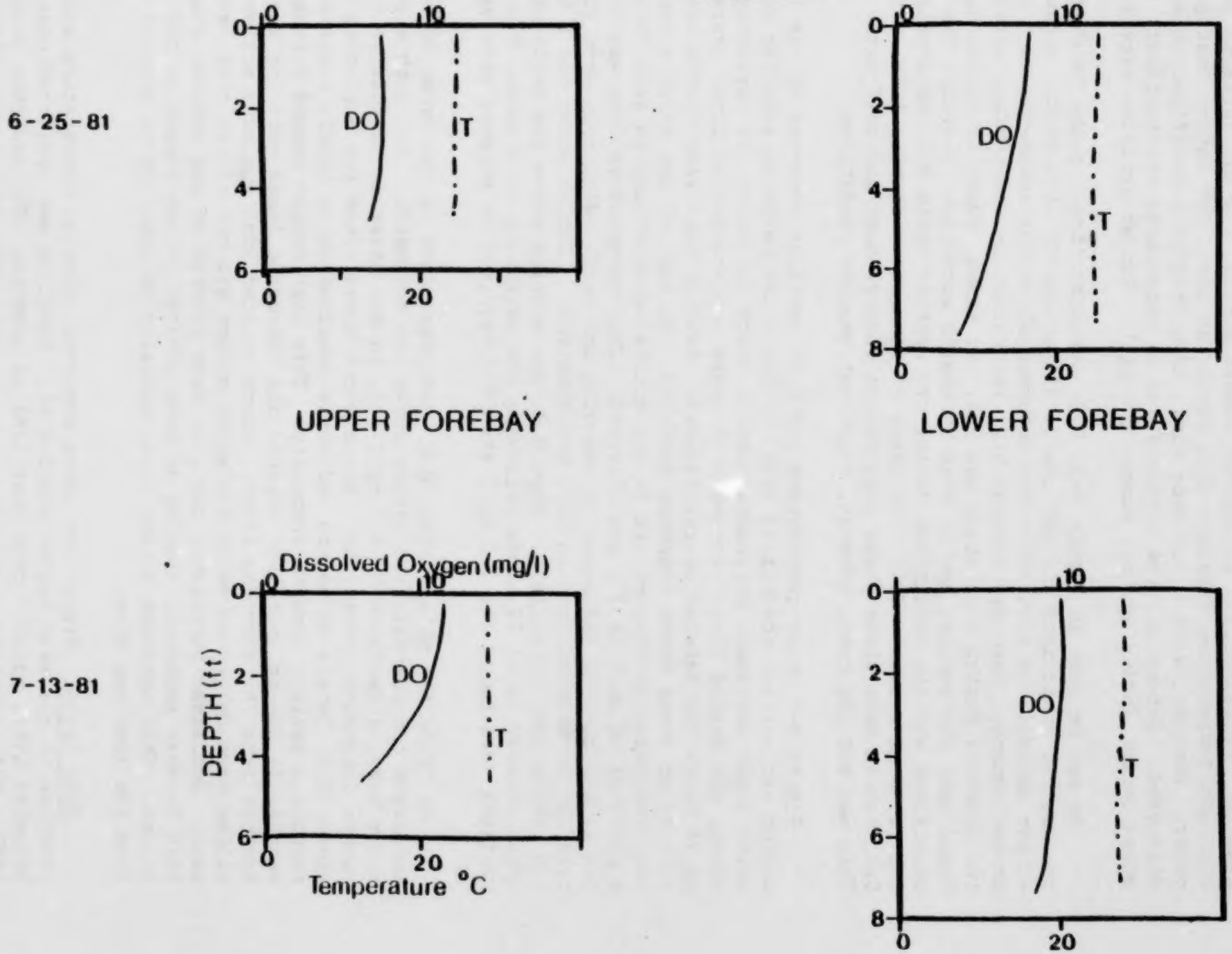


Figure 6-3: STORM RESPONSE TEMPERATURE & DISSOLVED OXYGEN PROFILES
- FOREBAYS -

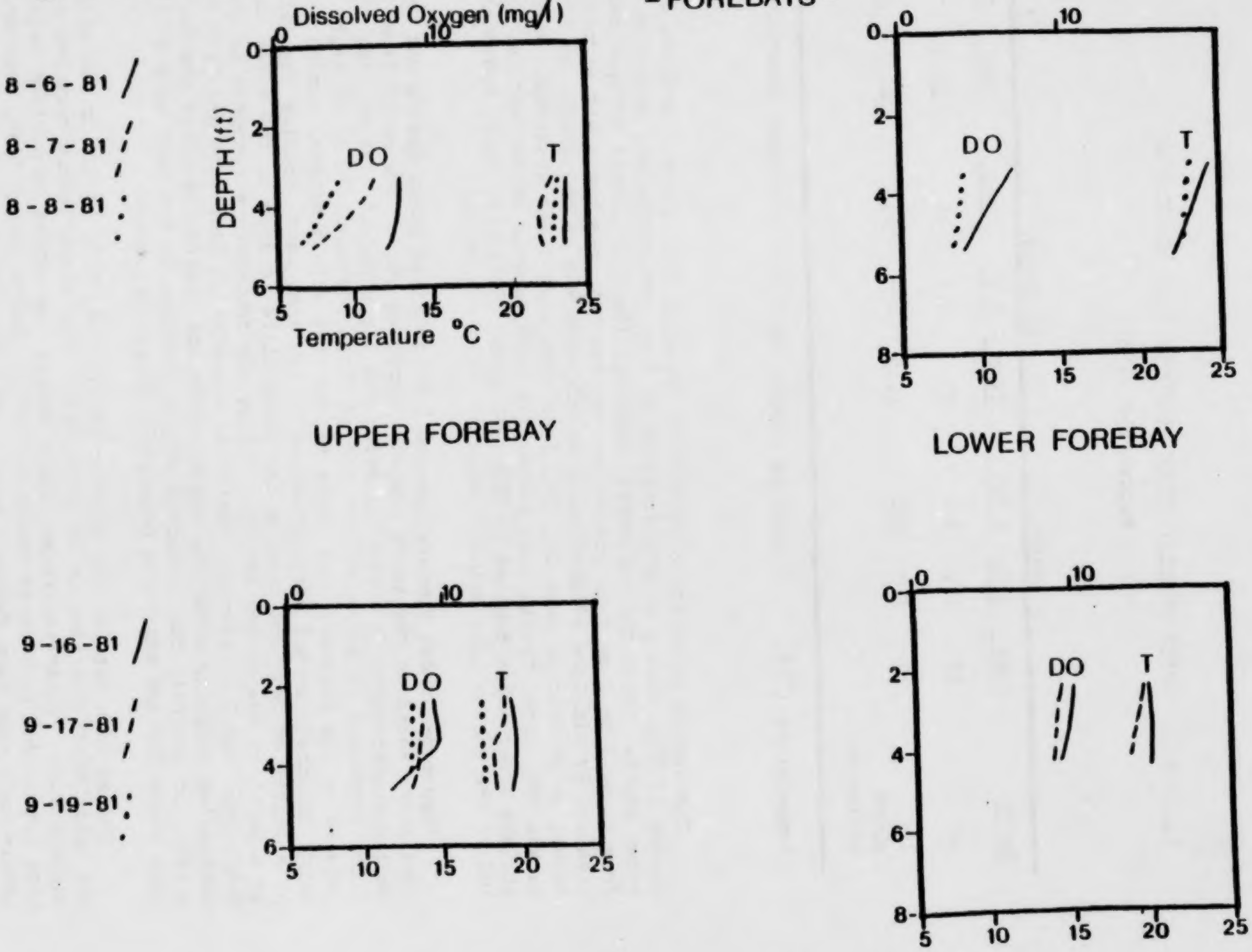


Table 6-5: UPPER FOREBAY STORM RESPONSE D.O. MONITORING

August 6-8, 1981

	24 Hours			48 Hours			72 Hours		
Depth	Temp.	D.O.	% Sat.	Temp.	D.O.	% Sat.	Temp.	D.O.	% Sat.
1m	23	7.4	85%	22	6.2	70%	22.5	7.5	86%
2m (above sediments)	23	7.2	83%	21.5	1.5	17%	21.5	2.3	26%

Temperature (°C), Dissolved Oxygen (mg/l), Percent Saturation

The winter temperature profile of December 1980 shows a uniform water column (3.5°C) with a slight decrease in D.O. concentrations over the 23 meter depth. Above the sediments, however, the D.O. levels dropped sharply from 11 mg/l to 2 mg/l in one meter. By mid-May, the basin was firmly stratified and by mid-June a substantial anoxic zone was established. As Figure 6-4 shows, at 30 feet on June 25, 1981 less than 1 mg/l was observed. According to the MDC, Upper Mystic Lake looses its hypolimnetic oxygen earlier than all the other lakes sampled by MDC (DiPietro, 1982). By July, approximately 50% of the entire Lake volume (below 30 feet) was anoxic.

Figure 6-5 shows temperature and D.O. profiles taken during wet weather conditions based on the storm response sampling runs. The solid lines represent concentrations 24 hours following the beginning of a storm, the dashed lines represent 48 hours and the dotted lines represent 72 or 96 hours (as labeled on the figure). All three storms that were monitored during this study impacted thermal stratification in the same way: cooling the epilimnion by a degree or two, and causing the thermocline to drop in the water column by a depth of one to two meters. Unlike the temperature response to the storms monitored, the D.O. response varied as illustrated in Figure 6-5 with D.O. increasing slightly after the August storm and decreasing after the September storm. In general, the dissolved oxygen profiles at the deep hole of the main basin did not exhibit a consistent storm influence.

During both wet and dry weather conditions, D.O. levels in the epilimnion and metalimnion (surface to 20 to 30 feet) were above levels required to support fish. Super-saturated values during the summer in surface waters were common due to photosynthetic activity. Below thirty feet, however, D.O. levels were near zero (below 1 mg/l). The temperature of the hypolimnion was adequate to support a cold water fishery but with near zero oxygen levels no fish can survive in the hypolimnion.

Figure 6-4: SEASONAL TEMPERATURE & DISSOLVED OXYGEN PROFILES – MAIN BASIN

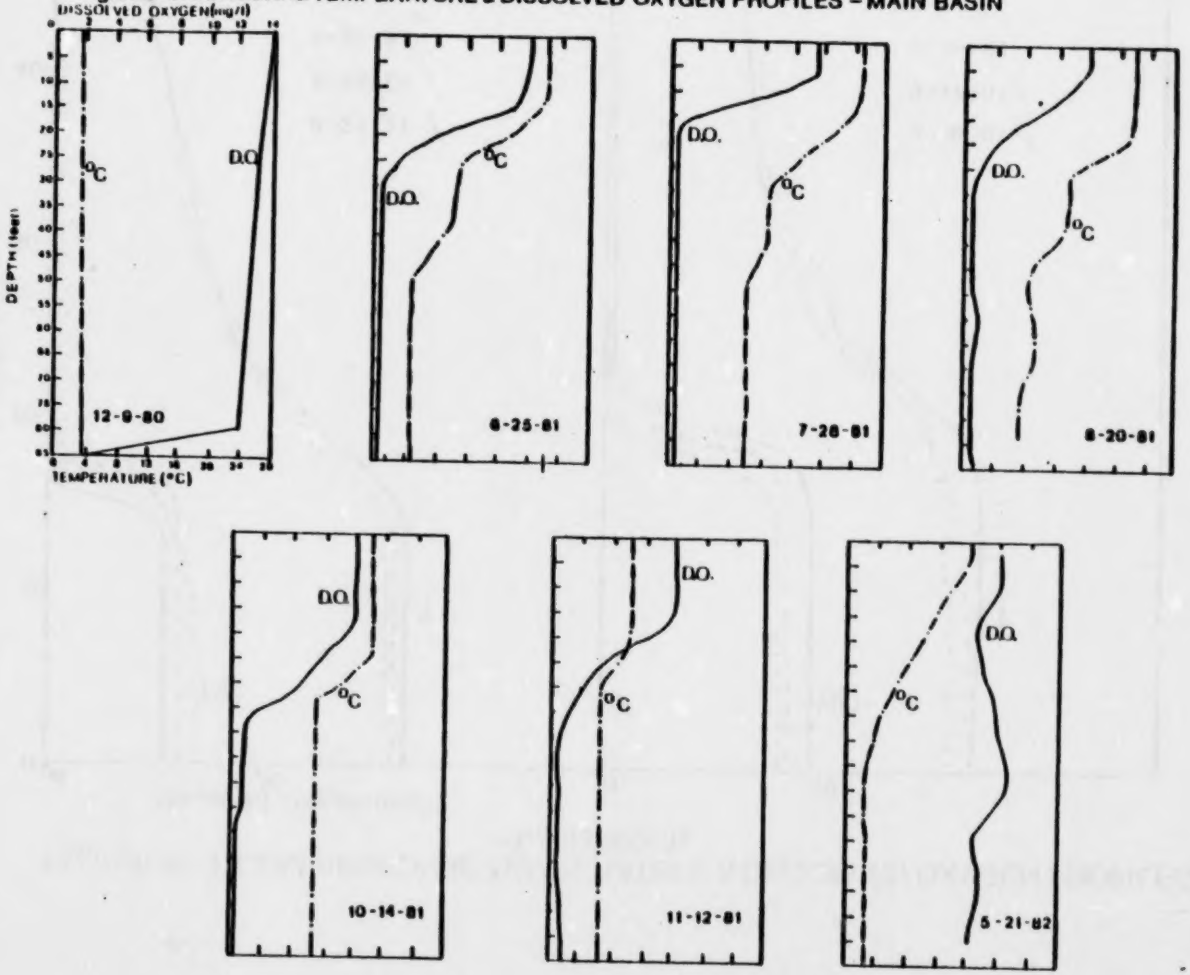
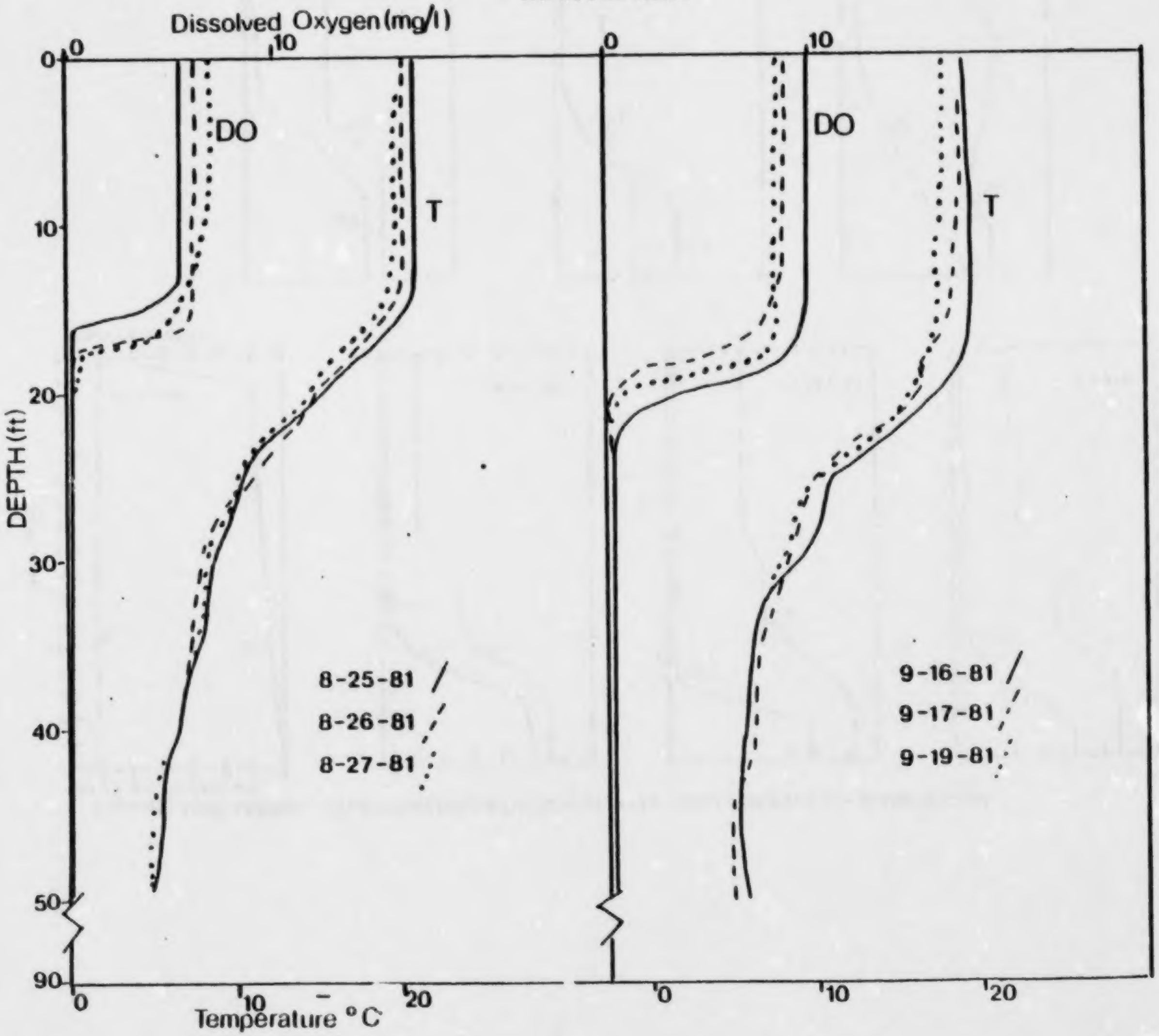


Figure 6-5: STORM RESPONSE TEMPERATURE & DISSOLVED OXYGEN PROFILES
-MAIN BASIN-



Finally, it is important to emphasize that even though the oxygen deficit in the hypolimnion is of concern, it represents only one area of oxygen stress in the entire lake system. When looking at the Lake in terms of water quality conditions or as a potential fishery, it is important to consider the forebays as well.

In-lake BOD_5 data are summarized on Table 6-6. The highest means and maximum values were observed in the upper forebay. Values decreased as waters moved through the Lake due to oxidation over time and dilution. The range of concentrations measured is much narrower than along the Aberjona.

Comparison with Historic Conditions

Historically, D.O. concentrations have not been a problem in the Aberjona River, except during times of low flow. A comparison of the ranges of in-stream D.O. concentrations data show no significant differences.

A comparison of BOD_5 concentrations in the Aberjona River over time shows a decrease in the maximum concentrations measured at Mishawum Road and USGS Gauge Stations, but an increase is evident at Washington Street.. Worsening of the combined manhole overflow problem into Sweetwater Brook is a possible cause for the Washington Street increase.

In terms of in-lake D.O. levels, there has been some improvement since 1967 when D.O. levels near zero were found at depth of 15 to 20 feet, encompassing roughly 65% of the lake volume (Mass. EDQE, 1975). Compared to in-lake BOD_5 data collected in 1976 to 1980, no significant difference between current levels and historic levels exist.

TABLE 6-6 : IN-LAKE BIOCHEMICAL OXYGEN DEMAND

	BOD (mg/l)	
Station	Mean	Range
Upper Forebay - St. 1		
wet	6.1	4.0 - 12
dry	7.0	2.0 - 12
Lower Forebay - St. 2		
wet	5.9	2.2 - 8.1
dry	6.5	2.8 - 9.3
Main Basin		
Epilimnion - St. 4A		
wet	4.8	1.6 - 8.1
dry	5.0	1.8 - 7.8
Metalimnion - St. 4B		
wet	3.5	1.5 - 6.1
dry	3.4	0.9 - 7.2
Hypolmnion - St. 4C	2.8	0.4 - 6.3
Outlet - St. 5		
wet	5.5	1.3 - 10.0
dry	4.7	0.9 - 8.7

6.3 PHOSPHORUS

Phosphorus Cycling and Controlling Conditions

Phosphorus is a naturally occurring element and is found in aquatic systems in the form of phosphate. Phosphate occurs as orthophosphate (inorganic reactive phosphate), condensed phosphate (pyro-, meta-, and poly phosphates) and organically bound phosphate.

Analytical differentiations between forms of phosphate are important to consider because they provide the basis for data interpretation. A definition of analytical terms follows:

> Total Phosphate: This is determined by digesting an unfiltered sample with acid which converts all the phosphorus in the sample into one measureable form (soluble orthophosphate). This determination quantifies the total amount of phosphate in the sample. In this report, total phosphate expressed as P is also referred to as total phosphorus.
>
> Total Soluble Phosphate: A sample is filtered, then digested. This measures the total quantity of dissolved phosphate in the sample; reported as total dissolved or soluble P.
>
> Total Particulate Phosphate: This is the difference between the total and dissolved phosphate fractions. It is the suspended P fraction.
>
> Orthophosphate: This is determined without sample digestion because it can be measured directly. Orthophosphate can occur both in dissolved (filtered) and particulate (unfiltered) forms, and is reported as such.

All phosphate results are expressed as an equivalent weight as phosphorus, regardless of their analytical form.

Phosphorus as phosphate is one of the major nutrients required for plant nutrition as well as for the health of other organisms. During the past 30 years, the belief has developed that increased crops of aquatic plants frequently are caused by increased supplies of phosphorus (U.S. EPA, 1976). Such phenomena is associated with eutrophication, the accelerated aging of a water body. It is important to recognize that phosphorus is not the sole cause of eutrophication but is frequently the key element since it generally is the limiting nutrient controlling plant growth as it is usually present in the least amount relative to need.

The limiting nutrient in an aquatic system is dependent on the nitrogen: phosphorus ratio. This ratio indicates which nutrient would be depleted first, thus, which nutrient would limit further growth. In general, when the ratio of nitrogen to phosphorus is above 7N:1P, a lake can be considered phosphorus limited; below 7N:1P, it can be considered nitrogen limited. The values of the ratio vary in the literature where some researchers use up to 17N:1P (Forsberg, 1980).

The phosphorus cycle is extremely complex and is governed to some extent by the trophic conditions present. Dissolved oxygen, the quantity of organic matter, sediment composition and water movements in the system all influence the phosphorus distribution.

Basically, under oxygenated conditions phosphorus is quickly and tightly bound to soils and suspended organic and inorganic particles. As suspended particles enter a lake system, they settle out to the sediments. The tendency of phosphorus to form insoluble compounds keeps it bound up and relatively unavailable. Decaying organic matter, settling algae, iron and aluminum oxides all bind with phosphorus, keeping it locked in the sediments. Bacterial activity at the sediment/water interface releases phosphate to the water column, where it either rapidly recycles back into the biotic community or recombines and settles out to the sediments.

Under oxygenated conditions, the largest fraction of phosphate, greater than 90%, is locked up either organically (in living or decaying cells) or is absorbed to particles which eventually settle out to the sediments (Wetzel, 1975). The smallest fraction under oxygen rich conditions is usually found as soluble orthophosphate. This is however the most significant form of phosphate since it is the most biologically reactive.

Aquatic vegetation, both rooted plants and algae, play a major role in phosphorus cycling. Algae have a capacity called a luxury load where they absorb and retain phosphate in their cells, hoarding more than they can use. At the same time, it leaks out of their cells only to be reabsorbed again. Rooted aquatic plants extract phosphate from the sediments directly, acting much like phosphorus pumps, storing excess phosphate in their leaves. This too leaks out to the water column. When algae and rooted plants die, some phosphate is released immediately by bacterial action, however the remainder is deposited in the sediments. Much of the material that becomes combined with the sediments remains there.

Fish and zooplankton also contribute to the phosphorus cycle. They ingest plankton and can excrete considerable quantities as phosphorus (Wetzel, 1975). However, this is difficult to quantify. Phosphates themselves seldom exert toxic effects on fish. Yet as a trigger for eutrophication, an abundance of phosphate can lead to water quality degradation which can affect a fish habitat.

Under anoxic conditions, the phosphorus cycle shifts. The iron oxide which keeps the phosphorus in the sediments is reduced, releasing soluble phosphate to the water column. The concentration of phosphate in the deeper waters of a lake can build up to such a degree that when the deeper waters are mixed with surface waters (through storm mixing or turnover) an algae bloom can result as a direct result of this mixing.

Metals and calcium also play a role in phosphorus cycling. Phosphate is known to form complexes, chelates or insoluble salts with a number of metal ions. This process is dependent upon the relative concentrations of each, the pH and the presence of other constituents such as organic ligands, as discussed in Section 6.6, sulfate and carbonate. The major metal ions which interact with phosphate are ferric iron, manganous manganese, zinc, and copper (Wetzel,1975).

Water Quality Significance

Phosphorus in aquatic systems is a major determinant of productivity. A phosphorus standard for the control of nuisance aquatic growth has not been established. There are, however, several rough guidelines that can be used.

(1) Total phosphate as P concentrations exceeding 0.025 mg/l in the surface waters of a lake may stimulate excessive growth of aquatic vegetation (U.S. EPA, 1976);

(2) Total phosphates as P should not exceed 0.050 mg/l in any stream where it enters a lake (U.S. EPA, 1976);

(3) Streams or flowing waters not discharging directly to lakes or impoundments should not exceed 0.10 mg/l total phosphate as P (U.S. EPA, 1976).

Another tool that can be used to determine the impact of phosphorus in a lake is the Vollenweider input-output model (Vollenweider, 1975). Vollenweider developed several models, however, his 1975 model has proven to be generally applicable to lakes in the northern temperate zone (CDM, 1982). This model not only defines the trophic status of a lake based on its annual phosphorus loading, depth, flushing rate and surface area but can be used as a tool for prescribing an annual phosphorus load that will improve trophic conditions.

The results of the Vollenweider model are presented graphically. The abscissa (X-axis) of the plot is the product of the mean lake depth (Z) and the flushing rate (E) expressed as meters per year, where the flushing rate is the average annual inflow divided by the lake volume. The ordinate (Y-axis) is the annual phosphorus loading expressed in grams/meter^2/year. Vollenweider plots are useful as general indicators of the eutrophic potential of a lake given various annual phosphorus loadings. The results of the plots should not, however, be misconstrued to be exact representations of the lake's trophic status since other lake characteristics also influence trophic conditions.

Existing Conditions - In-Stream

Table 6-7 summarizes total phosphorus and orthophosphate concentrations recorded for instream stations in the Upper Mystic Lake Watershed. The highest total phosphorus levels were found in Sweetwater Brook and the Boat Club Inlet with ranges of 0.3 to 6.1 mg/l and 0.07 to 12.2 mg/l, respectively. Sweetwater Brook receives sewer overflows from Stoneham and a similar problem is suspected at the Boat Club Inlet which could account for the high levels found there. Total phosphorus values are significantly higher during wet weather conditions, whereas orthophosphate concentrations are similar for dry and wet weather except for Sweetwater Brook and Washington Street. Again, the sewer overflows into Sweetwater Brook account for the differences at these two stations, Washington Street being below the confluence of the Aberjona and Sweetwater Brook. These trends indicate that urban runoff is a significant

TABLE 6-7 : IN-STREAM PHOSPHORUS CONCENTRATIONS (mg-P/1)

	Total Phosphorus (non-filtered)			Orthophosphate (non-filtered)		
Station	mean	median	range	mean	median	range
Mishawum Road						
wet	0.15	0.09	0.03-0.4	0.05	0.04	0.02-0.1
dry	0.06	0.05	0.03-0.09	0.05	0.04	0.04-0.07
Mill Street						
wet	0.11	0.1	0.08-0.15	0.04	0.02	0.008-0.08
dry	0.05	0.04	0.02-0.14	0.02	0.02	0.01-0.03
Washington St.						
wet	0.3	0.3	0.08-0.7	0.09	0.06	0.04-0.16
dry	0.21	0.13	0.08-0.52	0.16	0.12	0.05-0.31
USGS Gauge						
wet	0.1	0.1	0.04-0.2	0.05	0.04	0.03-0.07
dry	0.04	0.04	0.02-0.07	0.07	0.04	0.02-0.16
Sweetwater Brook						
wet	0.7	0.6	0.3-1.5	0.4	0.4	0.1-0.8
dry	2.6	3.2	0.46-6.1	2.0	2.4	0.24-4.8
Boat Club Inlet						
wet	0.63	0.62	0.07-1.2	0.21	0.21	0.22-0.19
dry	5.3	3.8	0.5-12.2	2.3	2.3	0.22-7.0
West Shore Inlet						
wet	0.15	0.08	0.05-0.34	0.04	0.05	0.00-0.06
dry	0.03	0.03	0.01-0.06	0.03	0.04	0.00-0.05

source of particulate phosphorus.

Of the instream guidelines listed above, the 0.05 mg/l total phosphorus value for streams entering a lake is applicable to the USGS gauge station on the Aberjona and to the Boat Club and West Shore Inlets. Wet weather medians at the Boat Club Inlet and USGS station both exceeded this guideline and also equaled or exceeded the 0.10 guideline for streams not discharging to lakes. All of the dry weather values recorded at the Boat Club Inlet also exceeded the 0.05 mg/l guideline for total phosphorus as did just the orthophosphate fraction at that station.

For the remainder of the sampling stations the 0.10 mg/l guideline is applicable. The wet weather medians at all stations exceeded that guideline except at Mishawum Road which was only slightly less (0.09 mg/l). Dry weather concentrations were also in excess at Washington Street and in Sweetwater Brook. In fact, all Sweetwater Brook total phosphorus and orthophosphorus values equalled or exceeded that total phosphorus guideline.

External Loads to Upper Mystic Lake. The annual loads of total phosphorus to the Upper Mystic Lake from various in-stream sources are shown on Table 6-8. The largest load comes from the Aberjona River, which contributes approximately 4,640 pounds of phosphorus per year. Of this baseflow, urban runoff and the Sweetwater sanitary connection contribute close to equal amounts. On a per acre basis the Boat Club Inlet contributes the greatest amount, with loads of 1.75 lbs/acre in comparison to the Aberjona River's 0.41 lbs/acre. Although this indicates that phosphorus pollution is more severe in the Boat Club sub-basin, the small size of the area makes the total load small relative to Aberjona River inputs. The loads from the West Shore inlet and direct drainage were the smallest for both total and per acre amounts.

Existing Conditions - Upper Mystic Lake

Table 6-9 summarizes the wet and dry weather phosphorus concentrations for Upper Mystic Lake. Total phosphorus means ranged from 0.04 to 0.27 mg/l which are very high for a lake system. Most relatively uncontaminated lakes are known to have surface waters that contain between 0.01 and 0.03 mg/l total phosphorus (Hutchinson, 1957). These in-lake values reflect the high phosphorus loadings to the Lake. All the total phosphorus means exceeded the previously mentioned guideline of 0.025 mg/l total phosphorus. Dissolved total phosphorus mean concentrations ranged from 0.02 to 0.20 mg/l. Most of the dissolved phosphate means also exceeded the 0.025 mg/l guideline for total phosphorus. This means that the dissolved fraction is high enough to cause vegetation problems, regardless of the particulate contribution. While total phosphorus concentration varied, higher values were observed following a storm. This reflects the higher phosphorus loading during wet weather conditions.

Orthophosphate mean concentrations ranged from 0.01 to 0.06 mg/l. These values are also very high for a lake system. Orthophosphate is generally low in lakes, accounting for only a small percentage of the total phosphorus. It is cycled very rapidly in the productive surface waters, ranging in concentrations from 0.001 - 0.005 mg/l in uncontaminated lakes (Wetzel, 1975). The mean

Table 6-8 ANNUAL TOTAL PHOSPHORUS LOADS TO UPPER MYSTIC LAKE FROM STREAM SOURCES
(lbs - P/yr)

Source	Aberjona River	Boat Club Inlet	West Shore Inlet	Direct Drainage
Baseflow	1,790	520	30	20
Urban Runoff	1,560	345	65	50
Sweetwater Brook Sanitary Contrib.	1.290	--	--	--
Total	4,640	865	95	70
Total Per Acre	0.41	1.75	0.20	0.13

Source: CDM, 1982

concentrations of orthophosphate in the forebays, at the outlet and hypolimnion also exceeded the 0.025 mg/l total phosphorus guideline. This is indicative of extremely eutrophic conditions. Orthophosphate is the most biologically significant form of phosphate, since it can be used directly by vegetation. As with in-stream concentrations, in-lake orthophosphate values did not vary significantly with weather condition.

N:P Ratio. An N:P ratio was calculated for Upper Mystic Lake based on average in-lake total nitrogen and total phosphorus values observed during this study, 4.0 and 0.08 mg/l, respectively. The ratio of 50:1 indicates that the Lake is phosphorus limited. Thus, the amount of phosphorus present is controlling plant growth in the lake.

Phosphorus Budget. A phosphorus budget was calculated for Upper Mystic Lake (see Table 6-10). All the loads except for sediment regeneration were calculated by Camp Dresser and McKee (1982). Sedimentation losses can be quite significant but are difficult to characterize (Wetzel, 1975) and are listed as unknown. The load from sediment regeneration is based on a worst case situation as discussed in Section 3.3. In actuality, the load could be as little as half of that listed in the table, making the sediments a less significant sources in comparison.

Based on this budget, approximately 6,500 lbs/yr enters the Lake and approximately 3,500 lbs/yr remains in the Lake as residual phosphorus. This portion is eventually deposited to the sediments. A little more than half of the load entering the Lake remains (55%). This is considered a very high residual phosphorus another indicator of the eutrophic condition of the Lake. Again, this reflects the high phosphorus loads to the Lake, since if inputs were decreased to the point where they

Table 6-9: SUMMARY OF UPPER MYSTIC LAKE PHOSPHATE CONCENTRATIONS

		Total Phosphate - P (mg/l)				Orthophosphate - P (mg/l)			
		Unfiltered		Filtered		Unfiltered		Filtered	
Station	Weather Condition	Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	Dry	0.07	0.05 - 0.12	0.03	0.02 - 0.05	0.04	0.02 - 0.06	0.02	1 sample
	Wet - day 1	0.08	0.07 - 0.12	0.03	0.02 - 0.04	0.03	0.02 - 0.05	0.01	0.010 - 0.014
	day 2	0.11	0.05 - 0.17	0.05	0.01 - 0.10	0.04	1 sample	0.01	1 sample
	day 3	0.27	0.13 - 0.54	0.14	0.26 - 0.35	0.03	1 sample	0.01	1 sample
2	Dry	0.06	0.02 - 0.09	0.02	0.01 - 0.03	0.03	0.01 - 0.06	0.01	1 sample
	Wet - day 1	0.09	0.07 - 0.12	0.02	0.01 - 0.04	0.03	0.02 - 0.03	0.01	0.00 - 0.02
	day 2	0.13	0.05 - 0.24	0.03	0.01 - 0.07	0.03	1 sample	0.03	1 sample
	day 3	0.12	0.06 - 0.18	0.07	0.03 - 0.13	0.02	1 sample	0.01	1 sample
4A	Dry	0.04	0.01 - 0.07	0.02	0.01 - 0.05	0.02	0.01 - 0.03	0.01	1 sample
	Wet - day 1	0.03	0.01 - 0.05	0.02	0.01 - 0.04	0.01	0.00 - 0.02	0.01	0.00 - 0.02
	day 2	0.05	0.02 - 0.12	0.04	0.01 - 0.10	0.02	1 sample	0.02	1 sample
	day 3	0.23	0.03 - 0.54	0.20	0.03 - 0.48	0.02	1 sample	0.02	1 sample
4B	Dry	0.03	0.01 - 0.08	0.03	0.01 - 0.05	0.01	0.00 - 0.02	0.01	1 sample
	Wet - day 1	0.04	0.01 - 0.06	0.02	0.01 - 0.02	0.01	0.00 - 0.03	0.01	0.00 - 0.01
	day 2	0.11	0.02 - 0.22	0.05	0.01 - 0.13	0.02	1 sample	0.01	1 sample
	day 3	0.08	0.05 - 0.15	0.03	0.01 - 0.06	0.01	1 sample	0.01	1 sample
4C	Dry	0.12	0.04 - 0.23	0.04	0.01 - 0.11	0.06	0.01 - 0.10	0.01	1 sample
	Wet - day 1	0.05	0.04 - 0.06	0.02	0.02 - 0.03	0.02	0.02 - 0.03	0.01	0.01 - 0.01
	day 2	0.04	0.04 - 0.05	0.02	0.02 - 0.02	0.02	1 sample	0.02	1 sample
	day 3	0.20	0.04 - 0.50	0.17	0.03 - 0.45	0.02	1 sample	0.01	1 sample
5	Dry	0.04	0.03 - 0.05	0.02	0.01 - 0.03	0.03	0.01 - 0.04	0.01	1 sample
	Wet - day 1	0.07	0.01 - 0.12	0.02	0.01 - 0.03	0.02	0.00 - 0.04	0.01	0.00 - 0.01
	day 2	0.08	0.01 - 0.13	0.04	0.02 - 0.05	0.03	0.03 - 0.03	0.02	1 sample
	day 3	0.22	0.02 - 0.62	0.19	0.02 - 0.54	0.02	1 sample	0.01	1 sample

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Table 6-10: UPPER MYSTIC LAKE PHOSPHORUS BUDGET

	Total Phosphate as P (lbs/yr)
Sources	
Aberjona River	4,640
Boat Club Inlet	865
West Shore Inlet	95
Direct Drainage	70
Precipitation*	47
Groundwater*	30
Sediment Regeneration	750
Losses	
Outflow**	2,950
Sedimentation	Unknown

* Precipitation and groundwater loads are based on total phosphate as P, 0.03 mg/l.

** Outflow load is based on total phosphate as P, 0.067 mg/l.

equalled or were less than the losses, the trophic condition would improve with time.

Vollenweider Plots. Vollenweider trophic status plots were developed for Upper Mystic Lake by Camp Dresser and McKee (1982). Since the two forebays behave differently than the main basin, the model was applied to the entire Lake system and separately to the main basin without the forebays. Table 6-11 displays the annual phosphorus loading used in the Vollenweider model (CDM, 1982). Figure 6-6 shows the Vollenweider results for both the main basin and the entire Lake system. Clearly the phosphorus loadings for both place the Lake in the eutrophic zone. In Chapter 8 this plot is used to estimate the reduction in loadings necessary to improve conditions.

Distribution Trends. The highest phosphorus concentrations in the Lake were found in the upper forebay. This was true under both wet and dry weather conditions and reflects the high concentrations in the Aberjona River. High concentrations were also found in the hypolimnion. A definite buildup of dissolved phosphorus in the hypolimnion was observed due to anoxic conditions.

TABLE 6-11: VARIABLES USED IN VOLLENWEIDER MODEL

	Main Basin*	Main Basin and Forebays**
Annual Phosphorus Loadings ($g/m^2/yr$)		
Aberjona River		
Urban runoff***	2.53	1.92
Baseflow	1.59	1.21
Direct Lake Drainage		
Urban runoff	0.41	0.31
Baseflow	0.51	0.38
Groundwater	0.03	0.02
Lake Bottom Sediments	0.67	0.50
Total	5.74	4.34
Mean Depth - Flushing Rate (m/yr)	47.9	39.2

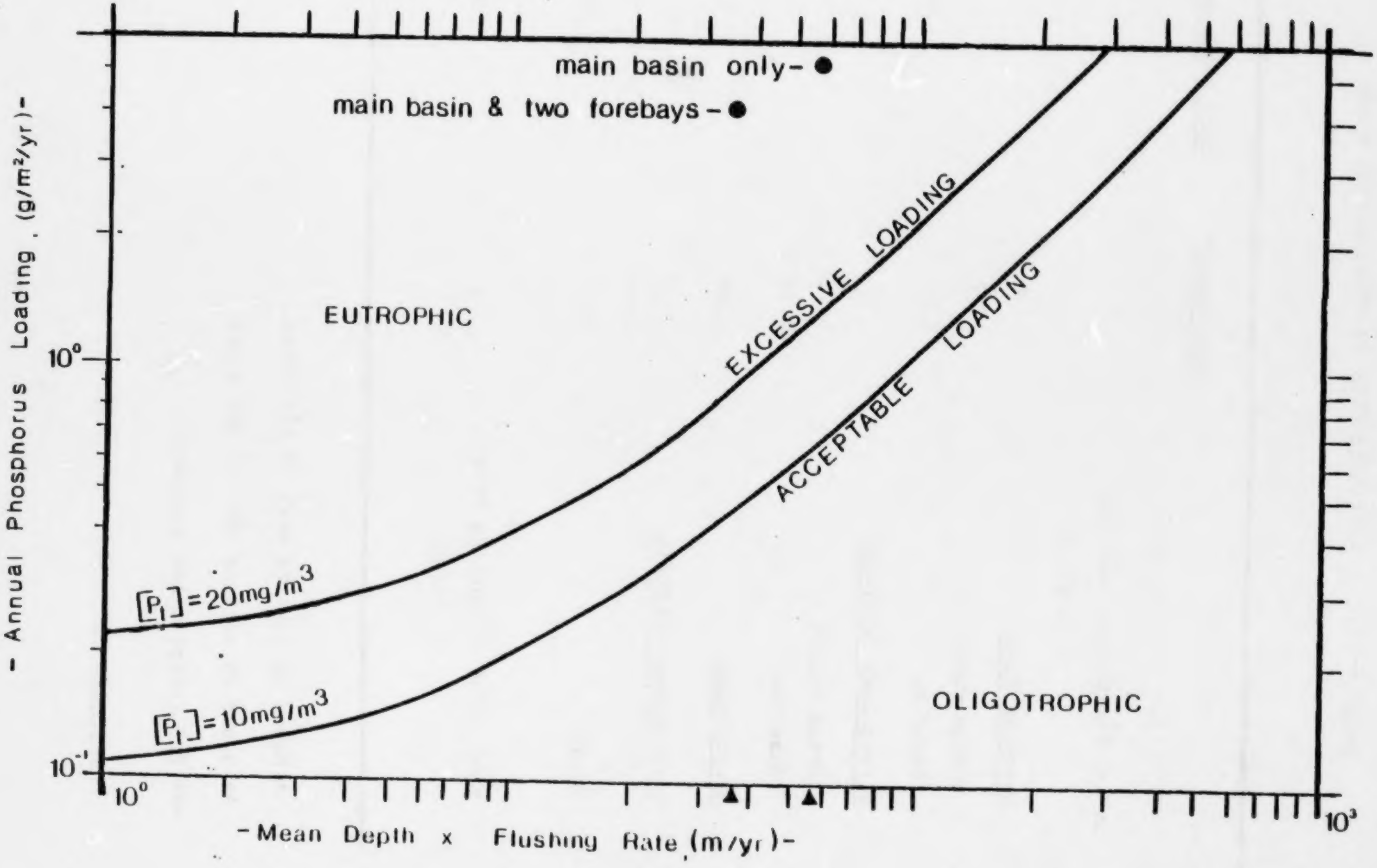
* Based on surface area of 126 acres.

** Based on surface area of 166 acres.

*** CSO contribution included.

Source: CDM, 1982

Figure6-6 : TROPHIC STATUS OF UPPER MYSTIC LAKE - VOLLENWEIDER PLOT



Based on Vollenweider (1975)

Table 6-12 presents the mean concentrations of total phosphorus by station. Only the dry weather hypolimnetic value is listed due to the sampling discrepency mentioned previously. In any case, the dry weather mean hypolimnetic value is believed to most accurately represent conditions in the deepest lake waters since samples were taken one half meter above the sediments. Temporary storm influences would not affect water at this depth. As can be seen, the wet weather means at the other stations were significantly higher than dry weather means.

Figure 6-7 shows the total and dissolved phosphate concentrations by station following storm events. This figure illustrates several trends that were observed following all the storms sampled. Again, the highest concentrations were in the upper forebay with a decrease in concentration toward the outlet. Another trend seen in Figure 6-7 is that 48 hours following the storms the phosphorus concentration at the outlet increased dramatically exceeding epilimnetic values indicating some mixing with hypolimnetic or metalimnetic water having higher levels.

The figure also indicates that most of the phosphorus in the forebays, following a storm, is in the particulate form. This shows that the forebays can play an important role as detention basins. It is interesting to note that on the second day of wet weather sampling, the dissolved fraction increases at the outlet. Again, this points to the hypolimnion as the source since dissolved phosphorus was the predominant form found in the hypolimnion.

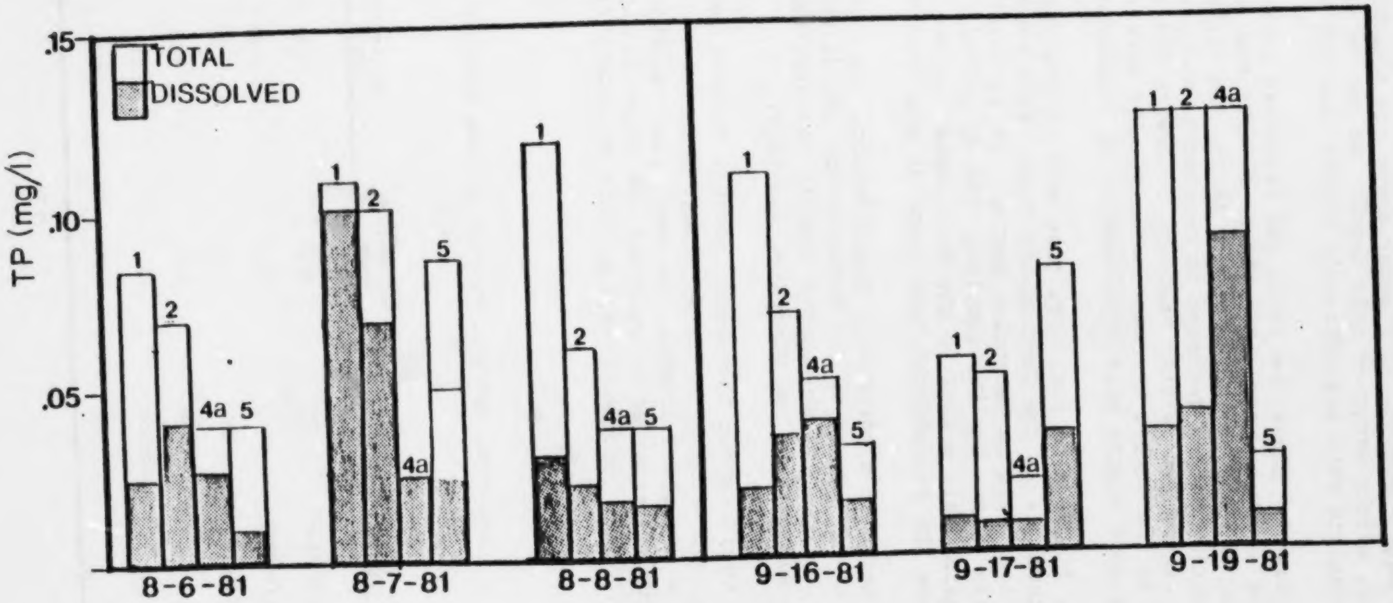
In terms of a horizontal distribution, the suspended particulate phosphorus appears to settle out in the forebays and the dissolved fraction washes through to the main basin. The phosphorus load to the hypolimnion is primarily algal bound phosphorus and the dissolved fraction.

One would expect the second forebay to have lower phosphorus concentrations than the upper forebay since settling, dilution and mixing of Aberjona River water would have occured. However, in some cases following storms, the second forebay concentrations equalled or exceeded the concentrations found in the first forebay. Two factors may combine to explain this occurence (1) increased storm flow decreases

Table 6-12: MEAN TOTAL PHOSPHATE AS P CONCENTRATIONS
(mg/l)

Station	Wet Weather Mean	Dry Weather Mean	Overall Mean
Upper Forebay	0.14	0.07	0.12
Lower Forebay	0.11	0.06	0.09
Main Basin - Epilimnion	0.09	0.04	0.07
Metalimnion	0.07	0.03	0.05
Hypolimnion	--	0.12	--
Outlet	0.12	0.04	0.09

Figure 6-7: WET WEATHER IN-LAKE PHOSPHORUS CONCENTRATIONS BY STATION



the forebay retention time thus allowing more particulate phosphorus to wash through to the second forebay; and (2) the concentrations at the Boat Club Inlet which are very high, enter the Lake in the second forebay and may serve to boost the concentrations in the second forebay.

Historic Comparison

A comparison with historic instream data shows a decrease in the maximum values recorded at Mishawum Road between 1973 and 1981. At Washington Street and USGS maximum values recorded in 1981 were generally higher than previously recorded values, again probably due to increases Sweetwater Brook levels.

Within the Lake, phosphorus data from the deep site taken in 1974 was compared to 1981 data. There was a very distinct difference in distribution between the years. In 1974, spring and early summer vertical profiles showed little change in concentration with depth. During the period of late summer through September, epilimnetic values exceeded hypolimnetic concentrations by as much as 0.04 mg/l. Anoxic sediment release was minimal, yet a very slight increase in hypolimnetic concentration was observed.

In 1981, the vertical phosphorus profiles showed a very different distribution. From spring until fall turnover, the hypolimnetic phosphorus concentration is triple that observed in 1974. Epilimnetic concentrations oscillated in 1981, but never exceeded hypolimnetic values as they did in 1974.

The concentrations in 1974 were high compared to most lake systems, but current levels are even higher. Sediment phosphorus values also increased over this same period (see Sediment section).

6.4 NITROGEN

Nitrogen Cycling and Controlling Conditions

Nitrogen occurs in several forms in aquatic systems. Commonly, it is found as dissolved molecular nitrogen (N_2), nitrite (NO_2), nitrate (NO_3), ammonia (NH_3 + NH_4) and organic nitrogen. The above notations are used throughout this section to designate the various species.

The cycling of nitrogen is largely controlled by microbial transformations and photosynthetic assimilation. The major processes involved are:

- Nitrogen fixation -- The assimulation of molecular nitrogen from the atmosphere by certain bluegreen algae and bacteria;
- Nitrification -- The biological oxidation of organic and inorganic nitrogen compounds from reduced states such as NH_4^+ to oxidized states, NO_2^- and NO_3^-, with oxygen being consumed in the process;
- Denitrification -- The biochemical reduction of oxidized species, NO_3^- and NO_2^-, to molecular nitrogen or ammonia;
- Plant Uptake -- The assimilation of nitrate or ammonia by algae and macrophytes.

The relative quantities of the various forms vary spatially and seasonally, being affected by changes in temperature, pH, oxygen content, water hardness, sunlight penetration, trophic level, and the nature of the microbial populations present.

Molecular Nitrogen. Molecular nitrogen is not particularly soluble in aquatic systems and this solubility decreases with increasing temperature. Bluegreen algae are able to fix molecular nitrogen if they contain heterocysts. This function is suppressed, however, in waters where nitrate and ammonia are readily available (Wetzel, 1975). Certain groups of heterotrophic bacteria and all photosynthetic bacteria also have the ability to assimilate molecular nitrogen, but little information is available on rates of assimilation (Wetzel, 1975).

Nitrate. Nitrate is the end-product of bacterial decomposition and nitrification of organic matter. It is the primary species of nitrogen utilized by algae and macrophytes. In surface waters, nitrate concentrations increase to a maximum in the spring and then decline during the growing season due to uptake by aquatic plants. According to Hutchinson (1957), 0.02 mg/l NO_3-N is a typical low summer value. Little nitrate is generally found in anaerobic hypolimnions since the nitrification process requires oxygen. Under anaerobic conditions, nitrate is microbially reduced to ammonia through denitrification. As an additional comparative value, nitrate plus nitrite in untreated municipal waste ranges from 0 to 6 mg/l with an average of 2 mg/l (Thomann, 1972).

Nitrite. In aquatic systems nitrite concentrations are usually very low, in the range of 0.0 to 0.01 mg/l NO_2-N. This is due to the rapid conversion of nitrite to nitrate during nitrification. In some cases, where there are low temperatures and high pH levels, nitrite accumulation may occur since the nitrifying bacteria which convert nitrite to nitrate, is less tolerant of these conditions than the bacteria which oxidize ammonia to nitrite (Wetzel, 1975).

Ammonia. Ammonia concentrations in lakes are extremely variable. The primary source of ammonia, excluding outside inputs, is from the bacterial decomposition of organic matter. Under anaerobic conditions which occur in the hypolimnion of many stratified lakes, the nitrification process in which the ammonia would be oxidized to nitrite cannot proceed. Consequently, an appreciable buildup of ammonia may occur as the period of stratification progresses. Anaerobic conditions can also accelerate the release of ammonia from the sediments due to the lowering of the sediment absorptive capacity (Wetzel, 1975). Ammonia accumulated in anaerobic hypolimnions can reach up to 10 mg/l (NH_3-N + NH_4-N) (Wetzel, 1975). This built-up ammonia is mixed with the upper waters during turnover, increasing the average lake concentration. Hutchinson (1957) cites data from a survey of Wisconsin lakes with surface water concentrations ranging from 0.09 to 0.41 mg/l (NH_3- N + NH_4-N) with the latter being considered very high. Similarly, McKee and Wolf (1963) state that unpolluted rivers generally have concentrations less than 0.2 mg/l. As an additional comparative value, concentrations in untreated municipal wastes range from 5 to 35 mg/l with an average of 28 mg/l (Thomann, 1972).

Ammonia, when dissolved in water, occurs as both ionized (NH_4^+) and unionized (NH_3 or NH_4OH) ammonia. In natural aquatic systems, the ionized form is most prevalent. Equilibrium between the two species is controlled by pH, temperature and, to a more limited extent in freshwater, ionic strength. The concentration of NH_3 increases as pH and temperature increase and decreases with increasing ionic strength. The approximate ratios of ionized to unionized ammonia at 18°C are:

pH 6	3000:1	
pH 7	300:1	
pH 8	30:1	
pH 9	1:1	(Hutchinson, 1957).

Organic Nitrogen. Nitrate or ammonia assimilated by organisms is converted into organic nitrogenous compounds. Wetzel (1975) compiled data from a number of lake studies, recording particulate organic nitrogen ranges from 0.02 to 2.35 mg/l N and dissolved from 0.05 to 1.55 mg/l N. As an additional comparative value, organic nitrogen concentrations in untreated municipal waste ranges from 5 to 35 mg/l N with an average of 20 mg/l N (Thomann, 1972). The total kjeldahl nitrogen method can be used to measure organic nitrogen. The test measures both organic and ammonia nitrogen, but the latter can be subtracted out.

Water Quality Significance

There are three major concerns regarding nitrogen levels in aquatic systems:

1) As a plant nutrient, it may be responsible for excessive algae and macrophyte growth;

2) Elevated levels of ammonia and nitrite may be toxic to aquatic life; and

3) Depletion of oxygen in the nitrification of organic and ammonia nitrogen.

The importance of nitrogen as a nutrient is dependent on the availability of the other two major nutrients, carbon and phosphorus. The carbon: nitrogen: phosphorus ratio of plants is around 40C:7N:1P by weight (Wetzel, 1975). Carbon is readily available in most aquatic systems as carbon dioxide, bicarbonate and organic carbon. Ratios used in the literature to determine which of the remaining two is the limiting nutrient, range from 7N:1P to 17N:1P.

The toxicity of ammonia to fish has generally been attributed to the unionized fraction (NH_3). As discussed in Chapter 4.0, EPA (1976) has established a criterion of 0.02 mg/l NH_3-N for protection of aquatic life. Information on the toxicity of ammonia to other aquatic life is limited. McKee and Wolf (1963) cite that 0.4 to 0.5 mg/l of total ammonia (NH_3-N + NH_4-N) caused the disappearance of the bluegreen algae *Aphanizomenon* and 8 mg/l has been found to be lethal to *Daphnia*. While EPA (1976) has not established a criterion for nitrite, they did provide several guidelines. For warm water fish, concentrations at or below 5 mg/l NO_2-N are considered safe, whereas for salmonids the protection level is 0.06 mg/l NO_2-N. These levels are above those which are normally present in natural aquatic systems. Ammonia and nitrite toxicity in fish are exhibited by a variety of pathological symptoms. A literature review, done as part of this project documenting these effects, is included in Appendix C.

The consumption of oxygen during nitrification was discussed in Section 6.2 where it was seen that it exerts a significant oxygen demand in Upper Mystic Lake.

Existing Conditions - In-stream

Table 6-13 summarizes in-stream nitrogen concentrations for both wet and dry weather conditions. Looking at the medians, which given the spread of the data are probably more indicative of normal conditions, certain trends are evident.

Nitrate and Nitrite: Along the Aberjona River both wet and dry weather nitrate concentrations were relatively high, with medians ranging from 1.0 to 3.0 mg/l. Additionally, wet weather values were generally higher than dry, implicating urban runoff as a source. Concentrations also tended to increase in the downstream direction probably due to the nitrification of ammonia.

High concentrations were also found in the West Shore and Boat Club Inlets, particularly in the latter. Unlike the Aberjona, dry weather concentrations were considerably higher than wet at both locations indicating that urban runoff is not the only source. A limited investigation conducted to identify other possible sources was discussed in Section 5.2.

Table 6-13: INSTREAM NITROGEN CONCENTRATIONS

	TKN-N (mg/l)			NO_2-N + NO_3-N (mg/l)			NH_3-N + NH_4-N (mg/l)		
Station	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
Mishawum Road									
- wet	14.5	6.4	3.8 - 67.7	2.0	1.8	1.3 - 3.2	4.5	4.3	2.1 - 6.5
- dry	15.6	13.0	11.0 - 20.0	1.3	1.0	0.7 - 2.1	13.0	11.0	10.0 - 16.0
Mill Street									
- wet	18.3	5.3	3.6 - 96.2	2.1	1.9	1.5 - 3.1	4.8	4.3	2.6 - 8.5
- dry	11.2	11.0	9.4 - 15.0	1.6	1.0	0.2 - 3.2	7.7	8.0	2.0 - 11.0
Washington Street									
- wet	16.9	5.2	1.3 - 84.4	2.2	2.1	1.3 - 3.6	3.1	2.2	1.0 - 7.2
- dry	7.3	7.3	4.2 - 10.0	2.7	2.1	1.6 - 5.1	5.9	5.9	1.9 - 8.0
USGS Gauge									
- wet	3.8	3.5	1.2 - 6.7	2.9	3.0	2.1 - 3.5	2.7	2.8	0.5 - 5.6
- dry	2.8	2.0	1.5 - 4.0	2.4	1.6	1.3 - 4.4	2.0	2.5	0.8 - 3.0
Sweetwater Brook									
- wet	5.1	4.1	1.7 - 10.6	2.0	1.8	1.1 - 2.9	0.8	0.4	0.2 - 1.2
- dry	10.7	8.0	1.6 - 25.0	0.9	0.6	0.1 - 2.3	8.1	8.0	0.8 - 21.0
West Shore Inlet									
- wet	1.9	1.0	0.6 - 4.0	1.8	1.9	1.6 - 1.9	0.05	0.02	0.02 - 1.0
- dry	0.5	0.4	0.2 - 0.9	2.8	3.0	2.0 - 3.8	0.06	0.02	0.00 - 0.09
Boat Club Inlet									
- wet	1.8	0.7	0.2 - 4.6	1.3	1.3	1.2 - 1.4	0.21	0.21	0.04 - 0.17
- dry	4.1	3.8	2.8 - 9.4	6.9	7.5	2.8 - 9.6	1.5	1.3	0.07 - 1.6

Ammonia. Wet and dry weather ammonia levels were also high along the Aberjona, particularly when compared to the 0.2 mg/l cited earlier for unpolluted rivers. Medians ranged from 2.2 to 11.0 mg/l. In the upper reaches, dry weather concentrations were more than twice wet weather levels. As discussed in Chapter 5.0, these levels are attributable to industrial waste disposal practices. Concentrations decreased in the downstream direction due to dilution and nitrification.

Dry weather values at Sweetwater Brook, median 8.0 mg/l, were also extremely high. Sewage overflows occurred upstream during both wet and dry conditions (see Chapter 5.0). On days that ammonia was high, phosphorus and coliform levels also indicated sewage contamination. A maximum of 21 mg/l NH_3-N was detected on August 19, 1981. The relatively low values recorded during wet weather were probably due to dilution.

The median at the West Shore Inlet, 0.02 mg/l, was the lowest concentration recorded in the entire Watershed. At the Boat Club Inlet, however, concentrations were ten times as high. As with nitrate, dry weather ammonia values at the Boat Club Inlet, median 1.3 mg/l, were significantly higher than wet weather, median 0.21 mg/l, again indicating some source other than urban runoff.

Total Kjeldahl Nitrogen. As is expected with the high ammonia levels recorded, TKN concentrations were also high and generally followed the same trends. The organic fraction was generally higher in wet weather, especially at Sweetwater Brook.

External Loads to Upper Mystic Lake. Table 6-14 presents loadings calculated for TKN, nitrate and ammonia. As seen there, baseflow and urban runoff from the Aberjona River are the major contributors of the various nitrogen species. Loadings at the Boat Club Inlet relative to West Shore Inlet loads, reflect the elevated concentrations discussed earlier.

Existing Conditions - Upper Mystic Lake

Nitrogen Budget. A nitrogen budget was computed for the Upper Mystic Lake as shown in Table 6-15. The detail of that budget is severely limited by the information available, particularly for losses. Denitrification to molecular nitrogen and subsequent loss to the atmosphere, and sedimentation can be responsible for significant losses, but are difficult to characterize (Wetzel, 1975). Additionally, nitrogen fixation, groundwater, and nitrification were not accounted for under sources, again because they are difficult to quantify. According to Wetzel (1975) when nitrate is plentiful, as it is in the Lake, N_2 fixation is generally not a significant source. An attempt was made to estimate groundwater inputs using dry weather stream characteristics, but given the unusually high concentrations of certain nitrogen species in the Aberjona and inlets, they are not necessarily representative of groundwater concentrations. Despite its limitations, the budget defines the relative magnitude of the various sources.

Table 6-16 summarizes Upper Mystic Lake nitrogen data for both dry and wet weather conditions. A detailed discussion of each species follows.

Table 6-14: ANNUAL LOADING TO UPPER MYSTIC LAKE (lb/yr)

	Aberjona River			Direct Drainage to Lake						Total
				West Shore I.		Boat Club I.		Direct		
	Baseflow	Sweetwater Sanitary Contribution	Urban Runoff	Baseflow	Urban Runoff	Baseflow	Urban Runoff	Baseflow	Urban Runoff	
Total Kjeldhal Nitrogen	130,330	11,865	84,460	330	620	1,310	760	240	450	230,365
Nitrate	40,890	5,210	77,355	2,455	1,240	2,705	1,215	1,785	905	133,760
Ammonia	138,000	1,160	75,900	845	675	60	70	615	490	217,815

Table 6-15: UPPER MYSTIC LAKE NITROGEN BUDGET

	Nitrogen (lbs/yr)		
Sources	TKN	NO_3-N	Total N
Aberjona River	211,250	123,400	334,650
Boat Club Inlet	3,690	2,220	5,910
West Shore Inlet	2,620	3,140	5,760
Direct Drainage	4,310	1,850	6,150
Precipitation*	3,260	60	3,320
Groundwater	unknown	unknown	unknown
Nitrogen Fixation			unknown
Nitrification	unknown	unknown	
Losses			
Outflow	140,910	77,500	63,410
Denitrification	unknown	unknown	unknown
Sedimentation	unknown	unknown	unknown

*Precipitation loads based on: NO_3-N, .04 mg/l, TKN, 21 mg/l.

Table 6-16: INLAKE NITROGEN CONCENTRATIONS

Station	Conditions	NO_3^--N (mg/l)		NO_2^--N (mg/l)		TKN (mg/l)		NH_3-N + NH_4^+ - N (mg/l)	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
1	Dry	1.5	0.7 - 4.4	0.112	0.055 - 0.190	2.4	1.7 - 3.3	1.71	0.32 - 3.40
	Wet - day 1	1.6	1.1 - 2.9	0.098	0.033 - 0.220	2.0	0.7 - 3.0	1.53	1.50 - 3.00
	- day 2	1.6	0.9 - 2.7	0.052	0.027 - 0.077	1.7	1.1 - 2.0	1.31	0.72 - 2.10
	- day 3	1.9	1.0 - 2.7	0.058	0.037 - 0.071	2.3	1.3 - 2.8	1.30	0.90 - 1.70
2	Dry	1.3	0.7 - 2.8	0.098	0.040 - 0.210	1.8	1.3 - 2.6	1.13	0.30 - 2.00
	Wet - day 1	1.5	1.0 - 2.7	0.089	0.029 - 0.220	1.9	1.2 - 2.6	1.23	0.60 - 1.90
	- day 2	1.6	0.9 - 3.0	0.037	0.025 - 0.054	1.3	0.6 - 1.8	0.97	0.70 - 1.50
	- day 3	1.9	1.2 - 2.5	0.042	0.026 - 0.056	2.0	1.9 - 2.1	0.93	0.80 - 1.00
4A	Dry	1.2	0.6 - 1.8	0.081	0.029 - 0.140	1.8	1.4 - 2.2	1.16	0.39 - 2.00
	Wet - day 1	1.7	1.0 - 3.1	0.052	0.025 - 0.150	2.3	1.7 - 3.2	1.48	1.10 - 2.00
	- day 2	1.4	0.9 - 2.2	0.029	0.023 - 0.040	1.6	0.9 - 2.0	1.48	0.95 - 2.00
	- day 3	1.6	1.0 - 2.1	0.029	0.021 - 0.044	3.1	1.8 - 5.6	0.78	0.30 - 1.10
4B	Dry	1.6	1.0 - 3.1	0.048	0.010 - 0.150	3.3	2.6 - 4.6	2.76	1.90 - 4.40
	Wet - day 1	1.9	0.9 - 2.9	0.031	0.012 - 0.060	2.8	2.6 - 3.0	2.28	1.80 - 2.60
	- day 2	2.2	1.1 - 3.2	0.023	0.016 - 0.033	2.4	2.0 - 2.9	2.33	1.50 - 3.60
	- day 3	2.3	1.0 - 3.6	0.020	0.009 - 0.027	2.8	1.9 - 3.3	2.10	1.20 - 3.20
4C	Dry	1.2	0.2 - 1.7	0.045	0.010 - 0.140	4.0	3.3 - 4.9	3.36	2.00 - 4.90
	Wet - day 1	1.9	1.0 - 3.2	0.062	0.015 - 0.180	3.3	2.7 - 3.4	2.53	1.90 - 2.90
	- day 2	2.9	2.3 - 3.4	0.026	0.015 - 0.036	2.8	3.1 - 3.1	2.70	1.70 - 3.70
	- day 3	2.6	1.9 - 3.3	0.023	0.013 - 0.037	3.4	2.7 - 3.8	2.53	1.50 - 3.80
5	Dry	1.0	0.7 - 1.4	0.090	0.030 - 0.150	1.8	1.3 - 2.3	0.71	0.10 - 2.00
	Wet - day 1	1.5	0.8 - 2.4	0.060	0.025 - 0.145	1.8	1.5 - 2.0	1.00	0.50 - 1.60
	- day 2	1.4	0.7 - 2.7	0.030	0.021 - 0.045	1.5	0.9 - 2.0	1.09	0.40 - 2.10
	- day 3	1.8	0.9 - 2.6	0.030	0.023 - 0.044	2.0	1.9 - 2.0	1.00	0.40 - 1.60

Nitrate. Nitrate concentrations, with means ranging from 1.0 to 2.9 mg/l NO_3-N, were high for a lake system where, as cited earlier, 0.02 mg/l is a typical summer value. These levels reflect the high nitrogen loadings to the Lake. While concentrations vary, no wet weather or spatial trends were observed. The levels in the hypolimnion (station 4C) were unusually high, means ranged from 1.2 to 2.9 mg/l, since under anaerobic conditions nitrate is generally reduced through denitrification. While a more detailed study would be required to determine the cause of this phenomenon, it is possible that growth of the anaerobic bacteria required to reduce the nitrate to ammonia is somehow being inhibited.

Nitrite. Nitrite levels, with means ranging from 0.002 to 0.112 mg/l, were also well above those generally found in lake systems (0.0 to 0.01 mg/l). Nitrite was highest in the surface waters, particularly in the forebays where it sometimes exceeded the 0.06 mg/l NO_2-N toxicity level for salmonoid fish. Toxicity levels for warm water fish were never exceeded.

Ammonia. Surface concentrations, with means ranging from 0.71 to 1.71 mg/l, were considerably higher than those cited earlier from the literature (0.09 to 0.41 mg/l). This is attributable to high levels coming in from the Aberjona and Boat Club Inlet. The concentrations decreased as the water traveled through the Lake due to dilution and nitrification. No significant differences were apparent between wet and dry weather concentrations. Under wet weather conditions both total and soluble ammonia were analyzed; the soluble fraction ranged from 80 to 100 percent of the total.

As seen in Table 6-16 surface water ammonia concentrations were significantly lower than levels in the hypolimnion. As discussed earlier, this result was expected due to the buildup of ammonia under anaerobic conditions in the hypolimnion. In fact, the levels found in the hypolimnion were less than those expected. Figure 6-15 also demonstrates the buildup of ammonia over time in the hypolimnion.

Given the concern with ammonia toxicity discussed earlier, unionized ammonia concentrations were calculated given in situ temperature and pH conditions. Table 6-17 presents these results for all surface water samples. Levels at lower depths were also calculated, but none exceeded the EPA toxicity criteria. Concentrations in the surface samples ranged from 0.001 to 0.230 mg/l NH_3-N, the latter being well above the EPA's 0.02 mg/l NH_3-N toxicity criteria. In all, eight data points or 16.0% of the surface water samples exceeded the criteria.

These incidences correspond to high temperature and pH conditions associated with hot, dry summer periods and high rates of photosynthetic activity. While these data definitely indicate that there is a potential for toxicity to fish, substantiating that effect would require bioassay tests simulating Lake conditions.

Considering the effect of ammonia on other aquatic life, the mean concentrations were well above the 0.4 mg/l (NH_3-N + NH_4-N) level which can cause the disappearance of Aphanizomenon; in fact, this species was identified during the course of this study (see Aquatic Life Section).

Table 6-17: INLAKE UNIONIZED AMMONIA CONCENTRATIONS

SURFACE WATER STATIONS

Station	Date	Temp (°C)	pH	Total Ammonia (NH_3 + NH_4^+-N) (mg/l)	Unionized Ammonia (NH_3-N) (mg/l)
1	6/23/81	22.5	6.5	3.00	0.005
	8/06	22.1	6.9	1.30	0.005
	8/07	22.3	6.8	1.10	0.004
	8/08	22.7	6.7	0.90	0.002
	8/20	22.7	8.1	0.32	0.018
	8/25	20.2	6.4	1.10	0.013
	8/26	18.5	7.8	0.72	0.016
	8/27	18.7	7.3	1.30	0.009
	9/16	19.0	6.7	0.70	0.001
	9/17	18.5	7.6	2.10	0.037*
	9/19	17.5	7.3	1.00	0.007
	9/28	16.0	7.7	1.60	0.023*
	10/14	11.4	7.5	2.10	0.014
	11/12	6.7	7.1	3.20	0.006
2	6/23	23.0	6.9	1.50	0.006
	8/06	24.0	7.2	0.90	0.008
	8/07	23.3	6.9	0.70	0.003
	8/08	23.5	7.4	0.80	0.010
	8/20	22.5	7.5	0.33	0.005
	8/25	21.0	6.8	1.90	0.005
	8/26	19.5	6.7	0.72	0.001
	8/27	20.2	7.5	1.00	0.013
	9/16	19.3	7.1	0.60	0.003
	9/17	19.0	7.6	1.50	0.027 *
	9/19	17.5	7.3	1.00	0.007
	10/14	11.7	7.6	2.00	0.016
	11/12	7.5	7.3	1.70	0.005
4A	6/23	22.0	7.4	1.60	0.018
	7/13	25.0	9.1	0.49	0.204 *
	8/08	23.5	8.8	0.30	0.073 *
	8/20	22.0	8.6	0.39	0.060 *
	8/26	20.0	7.2	0.95	0.006
	8/27	20.0	7.5	0.95	0.012
	9/16	19.0	7.4	1.20	0.011
	9/17	17.0	7.2	2.00	0.010
	9/28	16.0	7.6	0.92	0.011
	10/14	13.0	7.4	1.90	0.011
	11/12	9.2	7.3	1.60	0.006
5	6/25	24.0	7.7	1.60	0.004
	7/13	27.5	9.1	0.50	0.230 *
	8/06	23.5	8.7	0.40	0.082 *
	8/20	23.0	7.9	0.37	0.002
	8/25	21.0	7.2	1.20	0.008
	8/26	21.0	7.6	1.20	0.002
	8/27	20.0	7.5	1.60	0.002
	9/16	19.8	7.2	0.70	0.004
	9/17	19.0	7.3	2.10	0.015
	9/19	18.2	7.3	1.00	0.007
	9/28	16.0	7.5	0.94	0.001
	11/12	9.2	7.1	1.70	0.003

* Concentrations in Violation of the 0.02 mg/l Criteria.

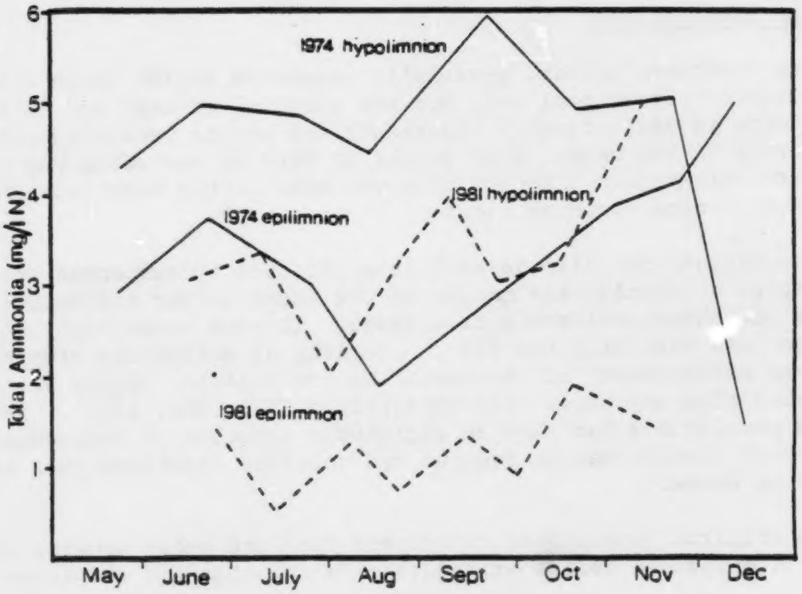
Total Kjeldahl Nitrogen. TKN values in the Lake ranged from 1.5 to 4.0 mg-N/l. While the ammonia fraction was high, the organic fraction was well within the range of literature values. As with ammonia, the highest levels were found in the hypolimnion and no significant wet weather trends were seen. Sediment samples were also analyzed for TKN and are discussed in Section 6.8.

Comparison to Historic Conditions

Ammonia and nitrate concentrations have decreased significantly along the Aberjona River since 1967. The 1967 data show an average ammonia concentration at Cedar Street (downstream of Mishawum Road) of 83.3 mg/l, and at USGS of 4.7 mg/l. Similarly, at the same locations, nitrate concentrations averaged 14.0 mg/l and 4.8 mg/l, respectively. This downward trend is particularly evident between 1967 and 1973; since that time decreases are observed but are much more gradual.

Ammonia concentrations in the Upper Mystic Lake have also decreased over time especially in the surface waters. Figure 6-8 is a comparison of 1974 and 1981 data collected in the epilimnion and hypolimnion at station 4. The unionized ammonia fraction was calculated for the twelve data points from 1974. A maximum level of 0.70 mg/l was found in the epilimnion in mid-August. Fifty-eight percent of the epilimnion samples exceeded the 0.02 mg/l criteria. As in 1981, no violations occurred in the hypolimnion. In-lake nitrate concentrations have not changed significantly since 1974.

Figure 6-8: Comparison of 1974 and 1981 Ammonia Concentrations



6.5 SOLIDS

Controlling Conditions

Solids exist in water in dissolved and particulate forms. Particulates are often called suspended solids since the matter is floating within the water column. Suspended solids include both organic and inorganic matter whereas dissolved solids are primarily inorganic salts with limited amounts of organic matter and other dissolved materials. To determine what quantity of the suspended solids are organic, the sample is volatilized in the laboratory. The part burned off is considered the organic fraction and the remaining residue the inorganic fraction. The total of all these categories of solids is termed total solids.

Solids enter aquatic systems from many sources. Runoff, wastewater discharges, groundwater inflow, and atmospheric fallout are some ways that dissolved and particulate solids are transported to surface waters. Decomposition of organic matter in aquatic systems is an internal source of solids.

Once in the water, solids are transported with the flow except when velocities are too slow to keep particulate solids suspended. Under these conditions, sedimentation occurs. The size and weight of a particle determines how rapidly and under what flow conditions it will settle out of the water column. During storm events when flows are elevated, scouring may occur and some of the previously settled solids will be resuspended. Dissolved solids can also be removed from the water column. Plant uptake, precipitation, and absorption to particulate solids are some ways this occurs.

Water Quality Significance

In Class B waters, solids, especially suspended solids which create turbidity, impact recreational uses and the survival of fish and other aquatic life. Turbidity is aesthetically unpleasant and may be severe enough to impair the transparency of the water, thus making it hard to see submerged objects. In areas where swimming is allowed this may make diving hazardous and can make it difficult to locate drowning people.

Fish populations may also be adversely affected by suspended solids. Large quantities of particulate matter in the water column can reduce fish growth rates and their resistance to disease. In some cases high solids concentrations can even kill the fish. Settling of solids can prevent fish egg and larvae development; if the particles are organic, oxygen depleted during decomposition may cause fish suffocation (U.S. EPA, 1976). Benthic invertebrate populations can also be negatively impacted by sedimentation. The diversity of species may be reduced and tolerant organisms such as worms can increase in number.

The EPA criteria established to protect fish and other aquatic life from the impacts of suspended solids states that "settleable and suspended solids should not reduce the depth of the compensation point of photosynthesis for aquatic life by more than 10% from the seasonally established norm for aquatic life" (U.S. EPA, 1976). In other words, the turbidity should not raise by more than 10% the depth at which the lack of light limits photosynthesis. Unfortunately, based on the data available, seasonal norms could not be calculated.

Suspended solids can also alter physical characteristics of the water column. Particles near the water surface are able to absorb heat thereby increasing the water temperature. Also, mixing within the water column may be inhibited since suspended solids have a stabilizing effect on water movement (U.S. EPA, 1976).

Dissolved nutrients, metals and other minerals commonly comprising dissolved solids can be present in quantities which affect the growth and longevity of aquatic organisms. The development of a dissolved solids criterion applicable to most aquatic environments is not possible since the toxic level would vary for each organism and constituent. Experiments show that lakes with concentrations exceeding 15,000 mg/l dissolved solids are not suitable for most freshwater fish (U.S. EPA 1976).

Existing Conditions - In-stream

A summary of solids data for in-stream stations under both wet and dry conditions can be found on Table 6-18. Total solids, suspended solids, and volatile suspended solids were measured.

Total Solids. The median concentrations of dry weather total solids for stations along the Aberjona River were fairly consistent, ranging from 324 to 446 mg/l. Overall ranges were from 261 to 560 mg/l. Unfortunately, wet weather total solids data were not collected, therefore changes in concentration, which might have been attributed to urban runoff influences, cannot be determined.

Sweetwater Brook and the two inlets to Upper Mystic Lake had slightly lower concentrations than the Aberjona River. The median dry weather values were in the 200 to 300 mg/l range. Also at the Boat Club and West Shore Inlets no significant differences were seen between dry and wet total solids concentrations.

Suspended Solids. There was greater variation in the median concentrations of suspended solids along the Aberjona River than was seen with total solids, especially under wet weather conditions. Values ranged from a low of 2.0 mg/l under dry conditions to a high of 62.0 mg/l during wet weather. At all stations, the wet weather concentrations were significantly higher than dry weather data. The biggest increase was seen at the Boat Club Inlet where the median level for wet days was 129 times the dry weather value. These increases in concentration are probably attributable to urban runoff.

Comparison of the suspended solids data with the total solids concentrations shows that under dry conditions, most of the solids in the tributaries were dissolved. The dry weather suspended solids fraction at all stations ranged from 0.4 to 4.1%, indicating that over 90% of the total solids are

Table 6-18: INSTREAM DATA ON SOLIDS FRACTIONS

Station	Total Solids (mg/l)			Suspended Solids (mg/l)			Volatile Suspended Solids (mg/l)		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
Mishawum Rd.									
Wet	--	--	--	33.1	30.0	14.0 - 53.4	11.1	11.1	4.8 - 17.6
Dry	358	324	290 - 482	5.8	5.5	3.0 - 9.5	3.7	4.0	2.5 - 4.5
Mill St.									
Wet	--	--	--	12.8	10.0	7.2 - 28.5	5.9	5.2	3.1 - 10.8
Dry	410	408	288 - 518	3.2	2.0	2.0 - 6.0	1.4	1.5	0.0 - 2.5
Washington St.									
Wet	--	--	--	117	62	17 - 272	44	23	9.7 - 107
Dry	364	386	280 - 458	8.6	5.5	4.0 - 22.0	5.6	3.5	2.5 - 13.0
U.S.G.S Gauge									
Wet	--	--	--	13.2	13.2	7.4 - 16.8	6.3	5.1	3.4 - 5.8
Dry	424	446	261 - 560	3.5	2.0	2.0 - 5.0	3.5	--	--
Sweetwater Brook									
Wet	--	--	--	167	188	29.2 - 305	76	79	18.8 - 185
Dry	316	296	276 - 420	17.0	12.0	4.5 - 33.0	12.5	9.5	0.0 - 31.0
Boat Club Inlet									
Wet	251	251	176 - 326	129	129	2.5 - 256	--	--	--
Dry	265	238	160 - 378	1.3	1.0	0.0 - 2.5	1.5	1.5	1.0 - 2.0
West Shore Inlet									
Wet	241	194	58 - 470	110	7	1 - 322	--	6	--
Dry	215	224	158 - 286	2.1	1.0	0.0 - 7.0	2.0	2.0	1.5 - 2.5

in solution. Under wet weather conditions the percentage varied with approximately 51 and 4% of the total solids as suspended solids at the Boat Club and West Shore Inlets, respectively. The lack of additional wet weather total solids information makes it hard to determine how runoff is influencing the suspended fraction.

Volatile Suspended Solids. These data help to show how much of the suspended solids is organic. For wet weather suspended solids, 49% was organic. Under dry conditions 73% organic material was found. The difference in these fractions indicates that the increase in suspended solids seen during wet weather is largely inorganic matter.

External Loads to Upper Mystic Lake. Only total suspended solids (TSS) loads to Upper Mystic Lake were calculated. The largest loads came from the Aberjona River where approximately 208,580 lb/year TSS were contributed from urban runoff, 154,700 lb/year from Sweetwater Brook sanitary overflows, and 94,555 lb/year in baseflow. The West Shore Inlet was the next largest contributor with 39,390 and 1,400 lb/year TSS entering the Lake from urban runoff and baseflow, respectively. Direct drainage to the Lake contributed 28,575 (urban runoff) and 1,045 (baseflow) lb/year TSS; and the Boat Club Inlet contributed the smallest amounts, with runoff adding 24,060 pounds of TSS each year to the baseflow annual load of 830 pounds. The total contribution was 553,075 lb/year TSS.

Existing Conditions - Upper Mystic Lake

A summary of solids data for in-lake stations under both wet and dry conditions can be found on Table 6- 19. Total solids, suspended solids and volatile solids were measured.

Total Solids. Total solids concentrations ranged from 201 to 1,054 mg/l with the highest concentrations observed in the upper forebay. Mean dry weather total solids ranged from 251 to 263 mg/l. Dry weather mean concentrations were fairly consistent at all stations with the exception of the upper forebay which was approximately 90 mg/l higher than the other mean station values.

Wet weather mean concentrations were higher than dry weather means, ranging from 351 to 392 mg/l. The increase of total solids during wet weather conditions reflects the increased loads from the Aberjona River. In the case of the second forebay, increased wet weather concentrations may be partially due to high loads from the Boat Club Inlet.

Suspended Solids. Suspended solids ranged from 0 to 35 mg/l with the highest concentrations, again, found in the upper forebay. Mean dry weather suspended solids ranged from 1 to 8 mg/l. Wet weather suspended solids ranged from 4 to 18 mg/l.

Volatile Solids. Volatile solids ranged from 0 to 110 mg/l. Mean volatile solids concentrations ranged from 38 to 52 mg/l with the highest mean at the outlet.

TABLE 6-19: INLAKE SOLIDS CONCENTRATIONS
(mg/1)

	Total Solids		Suspended Solids		Volatile Solids	
	Mean	Range	Mean	Range	Mean	Range
Station 1 - Upper Forebay						
dry	351	236-1054	8	2-17	38	30-46
wet	392	210-680	18	3-35		
Station 2 - Lower Forebay						
dry	263	244-318	7	3-14	45	5-78
wet	372	255-580	12	8-23		
Station 4A - Epilimnion						
dry	267	240-358	5	2-10	52	3-92
wet	351	238-730	12	16-18		
Station 4B - Metalimnion						
dry	270	246-302	2	0-6	38	0-72
wet	368	247-660	4	0-8		
Station 4C - Hypolimnion						
	352	250-810	1	0-3	40	1-70
Station 5 - Outlet						
dry	271	242-334	6	3-11	52	1-110
wet	354	201-619	8	2-13		

Comparison with Historical Conditions

A comparison with historic instream data indicates a marked decrease in the maximum concentration recorded between 1973 and 1981 at Mishawum Road. The range of values recorded during those two years at Washington Street and the USGS gauge are similar. Possibly the restriction placed on development in the Industri-plex area lowered the sediment loads attributable to erosion, and subsequently the suspended solids concentration at Mishawum Road decreased. The two samples collected in 1973 showed high concentrations of 100 and 25 mg/l suspended solids, and were reported to be elevated by construction activities upstream (Mass. WRC, 1974b). These levels were significantly higher than 1981 concentrations which ranged from 3 to 9.5 mg/l.

Very little historical solids data exist for the Lake. Outlet values for dissolved solids collected in 1971 ranged from 870 to 1,001 mg/l (Jason M. Cortell, 1971) which are higher than current levels.

6.6 METALS

Cycling and Controlling Conditions

The metals considered in this study are aluminum, arsenic, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, tin, and zinc. The transport, distribution, and form of these metals in aquatic systems is dependent on a number of environmental conditions including: organic matter content, pH, dissolved oxygen levels, inorganic compounds present, types of aquatic organisms present, and the hydraulic characteristics of the system. Specific influences depend on the chemical properties of each metal. Table 6-20 summarizes the occurrence and some major chemical properties of the metals analyzed in this study.

Metals occur in four major forms in aquatic systems: as ionic species in solution, physically attached to particulate matter as metal oxides, biologically bound, or chemically bound with organic compounds. Only a small percentage of the metals that enter a lake remain in solution as ionic metals (Neff et al., 1978).

Significant fractions of the metals found in both the water column and sedimentary phase are associated with organic matter (Davis, 1978). Ligands and humic compounds are two classes of organic molecules derived from plant, animal, and soil sources which have the ability to grip a metal ion. This gripping is called chelation. Once a metal is chelated, it takes a biological process or a major shift in water chemistry to unlock or release the metal from the organic compound.

A major fraction of the dissolved organic matter in lakes is composed of humic compounds. The large size and low solubility of humic compounds cause them to sink to the sediments, carrying chelated metals with them (Davis, 1978). In the case of copper, which is toxic to algae, humic acids lock up copper through chelation and can reduce its concentration to below toxicity threshold levels in lake systems (U.S. EPA, 1977e).

Suspended particles in aquatic systems are often coated with a film of organic compounds such as ligands which also chelate metals. As with humic compounds, the suspended particles carry the metals to the sediments (Davis, 1978). It has been shown that ligands can dramatically decrease the concentrations of available mercury, lead and copper in water through absorption on particulates (Neff, et al., 1978). Metals can also become physically attached to suspended particles as metal oxides and sulfides. The form in which metals enter the sediment phase is important since it will determine the rate and extent to which redistribution and recycling occur and will affect toxicity to aquatic organisms.

Another major factor influencing the distribution and form of metals in lakes is dissolved oxygen concentration. Under oxygenated conditions, many metals are bound to the sediments and only found in very trace amounts in the water column. Under anoxic hypolimnetic conditions, metals can undergo a chemical reduction and be released in dissolved ionic form. Iron and manganese are the first metals to be released followed by others under prolonged anoxic conditions. However, once turnover occurs and oxygen is mixed

Table 6-20: HEAVY METAL SUMMARY: OCCURRENCE AND CHEMICAL PROPERTIES

Aluminum:	It is a common element in soil but generally not found in unpolluted waterways. It is soluble in water; however, it readily combines with phosphorus and is absorbed to particulates as aluminum carbonate and precipitates out. Its form is very dependent on pH.
Arsenic:	It is insoluble in water, thus rarely encountered in unpolluted waterways. It tends to form toxic salts. The largest class of arsenic compounds are the organics and they are not naturally occurring.
Cadmium:	Generally not found in unpolluted waterways. It strongly absorbs to clays, muds, organic matter and some metal oxides, all of which precipitate out of solution. It dissolves readily in low pH and reacts with carbonate, hydroxides and sulfide ions.
Chromium:	It is rarely found in unpolluted waterways. It occurs in two forms [Cr^{+3}, Cr^{+6}]. The trivalent form tends to be absorbed by oxides such as MnO and precipitates out. The hexavalent form which is the more toxic form is readily absorbed by organisms, reacts with proteins and is found in soluble forms.
Copper:	It occurs in trace amounts in unpolluted waterways and strongly absorbs to clays, muds and organic matter. It is readily chelated and oxidized by organics. Its solubility is very dependent on pH shifts, alkalinity and temperature.
Iron:	It is a common element in soil and is commonly found in unpolluted waterways. Iron is insoluble in oxygenated waters, forms oxides which combine readily to other metals and phosphorus and precipitates out. Under anoxic conditions, iron is very soluble and can combine with sulfide.
Lead:	It occurs in trace amounts in unpolluted waterways. Most lead salts are of low solubility and found as lead carbonates and lead sulfates. Its solubility depends heavily on pH, hardness, organic matter and the presence of other metals. Bacteria can convert inorganic lead to an organic form.
Manganese:	It is a common element in soil, common in unpolluted waterways, and frequently found in association with iron compounds. It is commonly found in waterways as dioxides, oxides and silicates. Its solubility depends heavily on oxygen conditions, and it combines readily with other anions, metals and organic matter.
Mercury:	It is found in trace levels in water but it is very insoluble.
Nickel:	It is found in trace amounts in unpolluted waterways and most often is found as a salt which is soluble.
Tin:	It is rarely found in unpolluted waterways.
Zinc:	It is found in trace amounts in waterways. It usually occurs in nature as a sulfide and associates with the sulfides of other metals (lead, copper, cadmium and iron). Hardness, oxygen and temperature influence solubility greatly.

Sources: U. S. EPA, 1976; Skinner, 1976; Graber, 1978.

back into the entire water column, metals return to oxidated forms and return to the sediments.

Water Quality Significance

The presence of metals in aquatic systems is of concern relative to:

(1) potential toxicity to aquatic life, and
(2) suitability of fish for human consumption.

Ambient water quality criteria for the protection of fresh water aquatic life from the effects of metal toxicity, calculated for the Upper Mystic Lake, are listed in Table 4-4. The levels in the Lake should not exceed the 24 hour value when the concentrations of samples collected during one day are averaged. The 24 hour value is established to protect against chronic toxicity and the maximum level to protect against acute toxicity.

An additional means of measuring potential toxicity is comparison with chronic toxicity values for specific species. These are values which have been found to actually damage a particular fishery and consequently do not insure protection. Table 6-21 presents mean chronic toxicity copper values for four fish species. Similarly, for zinc, with a hardness range of 25 to 45 mg/l, the chronic toxicity level is 0.277 mg/l for rainbow trout and 0.852 mg/l for bluegills (U.S. EPA, 1980c). For lead, with a hardness of 28 to 41 mg/l, the literature values for chronic toxicity to early life stages for rainbow trout and bluegills are 0.24 and 0.092 mg/l, respectively (Davies, 1976; U.S. EPA, 1980e).

Table 6-21: MEAN CHRONIC TOXICITY VALUES FOR COPPER

Species	Concentrations (mg/l)
Brown Trout	.031
Bluegills	.029
Rainbow Trout	.019
Catfish	.015

Source: U.S. EPA, 1980d.

Ambient water quality criteria for the protection of human health from the toxic properties of heavy metals ingested through contaminated aquatic organisms are presented in Table 4-5. As discussed there, these are very rough guidelines. Additionally, the Federal Food and Drug Administration (FDA) has established a standard of 1 ppm in fish flesh for mercury (U.S. FDA, 1982).

Existing Conditions - In-Stream

A summary of metals data collected on the Aberjona River, and Boat Club and West Shore Inlets is presented on Tables 6-22 and 6-23. The EPA water quality criteria used in this study for the protection of aquatic organisms and humans consuming them were developed specifically for the Upper Mystic Lake based on its chemical characteristics and, therefore, no comparison will be made with in-stream data. Considering the medians and ranges in concentrations, several trends are evident from the instream data.

Along the Aberjona, downstream concentrations during both wet and dry weather generally decrease except for lead and manganese which were fairly constant. Increases in concentrations of aluminum, iron, lead and manganese detected at Washington Street can be attributed to the combined manhole overflows to Sweetwater Brook which joins the Aberjona upstream of Washington Street. Data collected at Sweetwater Brook support this conclusion. This decreasing downstream trend indicates that dilution with waters of lower concentrations or settling are occurring downstream of the Mishawum Road sampling station and that the area upstream of that site is an important source of metals. Investigation of specific sources within that area was beyond the scope of this study. For the Aberjona, wet weather concentrations for aluminum, copper, iron, lead, manganese and zinc are generally higher than dry weather implicating runoff as an important source.

Metals concentrations on the inlets are generally lower than in the Aberjona particularly for aluminum, copper, lead, iron, zinc and manganese. This would be expected since the inlet drainages are primarily residential whereas the Aberjona has significantly more commercial and industrial development especially in the upper Watershed. Additionally, groundwater inputs and release from sediments may be important.

A few metals were not present at laboratory detection limits using atomic absorption by direct aspiration including cadmium, chromium, and tin during dry and wet weather, and aluminum, copper, lead and nickel during dry weather alone. A partial sampling survey was conducted on May of 1982 using a more precise analytical method (atomic absorption by furnace). The results of this wet weather sampling run are presented on Table 6-24. Cadmium and chromium were both found while tin was still below the lower detection limit.

External Loads to Upper Mystic Lake. Annual loads of metals entering the Upper Mystic Lake are presented on Table 6-25. It should be noted, that these loads were calculated based on relatively few samples (see Table 6-22) and, consequently, while they are useful in considering the relative contribution of the various sources, they should be considered rough estimates. As would be expected, these metals which had increased wet weather concentrations also had significant wet weather loads (urban runoff and Sweetwater sanitary contribution).

Table 6-22: ABERJONA RIVER IN-STREAM METALS CONCENTRATIONS
(mg/l)

Metal	Mishawum Road		Hill Street		Washington Street		USGS Gauge		Sweetwater Brook	
	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Aluminum										
no. samples	5	5		5	5	4	16	9	5	5
median	0.95	<0.1	0.6	<0.1	2.3	<0.1	0.25	<0.1	1.8	<0.1
range	0.65-2.2	<0.1-0.16	0.38-0.95	<0.1-0.16	0.72-7.5	<0.1-0.16	0.11-1.5	<0.1-0.12	0.43-8.5	<0.1-0.17
Arsenic										
no. samples	4	5	1	5	2	4	5	6	2	5
median	0.012	0.04	0.012	0.02	0.020	0.015	0.008	0.015	---	0.01
range	0.005-0.045	0.007-0.04	---	0.007-0.03	0.018-0.023	0.008-0.02	0.004-0.018	0.002-0.02	<0.001-0.003	<0.002-0.03
Cadmium										
no. samples	3	5	2	4	3	3	5	5	2	1
median	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
range	<0.01-0.01	<0.01- 0.01	<0.01- 0.01	<0.01- 0.01	<0.01- 0.01	<0.01- 0.01	<0.01- 0.01	<0.01- 0.01	<0.01- 0.01	<0.01- 0.01
Chromium										
no. samples	1	4	0	3	1	3	3	2	0	1
median	<0.02	<0.02	---	<0.02	0.02	<0.02	<0.02	<0.02	---	<0.02
range	----	<0.02	---	<0.02	---	<0.02	<0.02- 0.02	<0.02- 0.02	---	<0.02
Copper*										
no. samples	5	5	4	5	5	5	15	5	4	5
median	0.36	0.01	0.07	<0.01	0.14	<0.01	0.13	<0.01	0.12	0.01
range	0.25-3.0	<0.01-0.01	0.05-0.08	<0.01-0.01	0.12-0.18	<0.01-0.08	0.01-0.41	<0.01-0.02	0.06-1.1	<0.01-0.02
Iron										
no. samples	5	5	4	5	5	4	12	8	4	5
median	2.4	2.6	2.25	1.1	4.5	0.86	0.96	0.54	4.75	0.60
range	2.3-3.2	1.4-2.6	1.8-2.7	0.7-1.2	2.2-13.0	0.02-1.0	0.62-2.4	0.05-1.1	1.7-15.0	0.22-1.70
Lead										
no. samples	5	5	3	5	5	4	13	7	1	5
median	0.06	<0.03	0.05	<0.03	0.24	<0.03	0.10	<0.03	0.19	<0.03
range	0.03-0.1	<0.03- 0.03	0.05-0.32	<0.03- 0.03	0.06-0.50	<0.03- 0.01	0.03-0.18	<0.03-0.04	<0.03-0.62	<0.03-0.11
Manganese										
no. samples	5	5	3	5	5	4	8	7	1	5
median	0.44	0.46	0.35	0.46	0.56	0.29	0.28	0.23	0.24	0.08
range	0.2-0.61	0.30-1.0	0.3-0.71	0.26-0.55	0.53-0.63	<0.01-0.31	0.13-0.75	0.01-0.40	0.15-0.37	0.06-0.14
Nickel										
no. samples	3	5	2	5		4	5	8	2	5
median	0.03	<0.02	---	<0.02	<0.02	<0.02	<0.02	<0.02	---	<0.02
range	0.01-0.05	<0.02 - 0.02	<0.02-0.04	<0.02 - 0.02	<0.02	<0.02 - 0.02	<0.02 -0.03	<0.02 -0.02	<0.02-0.06	<0.02 - 0.02
Tin *										
no. samples		5		5		4		4		5
median	0.006	<0.5	0.005	<3.5	0.011	<3.5	0.003	<0.5	0.005	<0.5
range	<0.005-0.01	<0.5- 0.5	<0.005-0.03	<0.5- 0.5	<0.005-0.4	<0.5- 0.5	<0.005-0.136	<0.5- 0.5	<0.005-0.01	<0.5- 0.5
Zinc										
no. samples	5	5	5	5	5	4	18	7	5	5
median	0.14	0.03	0.13	0.04	0.25	0.035	0.06	0.02	0.30	0.02
range	0.09-2.1	0.02-0.13	0.10-0.34	0.03-0.07	0.21-0.58	0.01-0.08	0.03-0.14	0.01-0.06	0.15-0.61	0.01-0.14

* Wet weather samples analyzed by furnace, dry weather by flame.

Table 6-23: SMALLER TRIBUTARY IN-STREAM METALS CONCENTRATIONS

(mg/l)

Metal	Boat Club Inlet		West Shore Inlet	
	Wet	Dry	Wet	Dry
Aluminum				
no. samples	1	13	1	13
median	2.0	<0.1	5.1	<0.1
range	-	<0.1 - <0.1	-	<0.1 - 0.16
Arsenic				
no. samples	3	9	3	8
median	<0.002	0.002	<0.002	<0.002
range	<0.002 - 0.01	0.002 - 0.02	<0.002 - 0.016	<0.002 - 0.02
Cadmium				
no. samples	2	5	2	5
median	<0.01	<0.01	<0.01	<0.01
range	<0.01 - <0.01	<0.01 - <0.01	<0.01 - <0.01	<0.01 - 0.01
Chromium				
no. samples	1	5	1	5
median	<0.02	<0.02	<0.02	<0.02
range	-	<0.02 - <0.02	-	<0.02 - <0.02
Copper				
no. samples	5	7	5	7
median	0.01	0.01	0.01	<0.01
range	<0.01 - 0.05	<0.01 - 0.12	<0.01 - 0.05	<0.01 - 0.01
Iron				
no. samples	3	9	3	8
median	0.15	0.17	0.17	0.06
range	0.15 - 2.2	0.09 - 1.5	0.15 - 3.8	<0.02 - 0.37
Lead				
no. samples	3	8	3	8
median	<0.02	<0.02	<0.03	<0.02
range	<0.02 - 0.31	<0.02 - 0.06	<0.02 - 0.21	<0.02 - 0.05
Manganese				
no. samples	3	9	3	9
median	0.06	0.02	<0.01	<0.01
range	0.01 - 0.20	<0.01 - 0.10	<0.01 - 0.60	<0.01 - 0.01
Nickel				
no. samples	3	8	3	3
median	<0.02	<0.02	0.03	<0.02
range	<0.02 - 0.03	<0.02 - 0.02	0.03 - 0.03	<0.02 - <0.02
Tin				
no. samples	2	4	2	4
median	<0.5	<0.5	<0.5	<0.5
range	<0.5 - <0.5	<0.5 - <0.5	<0.5 - <0.5	<0.5 - <0.5
Zinc				
no. samples	3	7	3	7
median	0.01	0.03	0.01	<0.01
range	0.01 - 0.14	<0.01 - 0.12	0.01 - 0.26	<0.01 - 0.01

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Table 6-24: UPPER MYSTIC LAKE METAL CONCENTRATIONS
(Atomic Absorption: Furnace Mode)

Station	Cadmium (mg/l)	Chromium (mg/l)
In-lake		
1	0.004	0.045
2	0.003	0.008
4A	0.003	0.008
4B	0.002	0.002
4C	0.004	0.004
5	0.001	0.027
IS6-USGS Gauge	0.001	0.015
West Shore Inlet	0.002	0.010
Boat Club Inlet	< 0.001	0.018

(Samples collected 5/21/82 under wet weather conditions.)

Existing Conditions - Upper Mystic Lake

Table 6-26 summarizes the in-lake metals concentrations as detected during the 1981 surveys. Cadmium and chromium are not included since all but one value recorded were below the atomic absorption by direct aspiration detection limit. That one exception was 0.02 mg/l cadmium recorded at station 5 during wet weather. Table 6-24 presents the results of the May 1982 survey in which the more precise furnace method was used.

Several trends are evident from these data: (1) aluminum, iron, lead, manganese, and nickel were generally higher during wet weather; (2) manganese and iron were high in the hypolimnion indicating anoxic sediment release; and (3) aluminum, arsenic, manganese and iron were higher in the upper forebay that at other surface stations.

The metal concentrations recorded were compared to the EPA's 24 hour average and maximum toxicity criteria, and estimated thresholds for intermittent exposure for protection of aquatic life as listed in Table 4-4.

Twenty-Four Hour Average Toxicity Criteria. Table 6-27 summarizes the metals that exceeded the 24 hour average or chronic criteria during dry and wet weather conditions at each station and lakewide. These included copper, lead and zinc. For example, 100% of the wet weather samples collected at station 1 (upper forebay) violated the copper criterion. As can be seen, the percentages of violation were high and fairly evenly distributed across the Lake. Lakewide, 85% of the copper samples exceeded the criteria as did 52% of the zinc and 40% of the lead. The percentage of lead violations tended to decrease slightly from station 1 (upper forebay) to station 5

Table 6-25: [illegible] O UPPER MYSTIC LAKE
[illegible] r)

Metal	Aberjona River Baseflow	Urban Runoff	Sweetwater Brook Sanitary Contribution	West Shore Inlet Baseflow	Urban Runoff	Boat Club Inlet Baseflow	Urban Runoff	Direct Drainage Baseflow	Urban Runoff	Total
Aluminum	2,550	1,565	5,220	40	280	25	450	10	205	10,365
Arsenic	100	335	20	7	3	4	4	5	3	481
Cadmium	*	*	*	*	*	*	*	*	*	*
Chromium	*	*	*	*	*	*	*	*	*	*
Copper	*	485	870	5	20	5	40	4	15	1,444
Iron	17,890	11,650	8,700	140	315	40	370	105	230	39,440
Lead	*	330	350	*	40	3	20	*	30	771
Manganese	5,110	19,480	870	30	30	2	55	20	20	25,617
Nickel	510	*	90	5	3	*	5	4	3	620
Tin	*	*	*	*	*	*	*	*	*	*
Zinc	1,020	485	870	20	35	2	15	15	25	2,487

* Presence not detected, therefore no loads were estimated.

Source: CDM, 1982.

Table 6-26: UPPER MYSTIC LAKE METAL CONCENTRATIONS

Atomic Absorption: Direct Aspiration

		ALUMINUM			ARSENIC			MANGANESE		
Station	Weather Condition	Median (mg/l)	Range (mg/l)	no. samples	Median (mg/l)	Range (mg/l)	no. samples	Median (mg/l)	Range (mg/l)	no. samples
1	dry	<0.1	<0.1 - 0.15	8	0.007	<0.002 - 0.020	6	0.14	<0.01 - 0.24	8
	wet	0.31	<0.1 - 0.56	8	0.008	0.006 - 0.010	2	0.33	0.31 - 0.34	2
2	dry	<0.1	<0.1 - 0.25	8	0.006	<0.002 - 0.020	6	0.10	0.04 - 0.24	8
	wet	0.17	<0.1 - 0.56	8	0.006	0.004 - 0.007	2	0.19	0.18 - 0.20	2
4A	dry	<0.1	<0.1 - <0.1	8	0.004	<0.002 - 0.010	6	0.06	0.03 - 0.11	8
	wet	0.11	<0.1 - 0.22	8	0.003	<0.002 - 0.005	2	0.13	0.08 - 0.17	2
4B	dry	<0.1	<0.1 - <0.1	8	0.002	<0.002 - 0.010	6	0.17	0.08 - 0.59	8
	wet	0.27	0.1 - 0.33	4	0.003	<0.002 - 0.005	2	0.14	0.07 - 0.20	2
4C	dry	<0.1	<0.1 - <0.1	8	0.006	<0.002 - 0.020	6	1.10	1.12 - 1.90	8
	wet	0.19	0.1 - 0.28	4	0.002	<0.002 - 0.004	2	0.60	0.24 - 0.90	2
5	dry	<0.1	<0.1 - 0.93	8	0.002	<0.002 - 0.020	6	0.06	0.03 - 0.15	9
	wet	0.3	<0.1 - 0.33	4	0.006	<0.002 - 0.010	3	0.06	0.03 - 0.16	5

		COPPER			IRON			LEAD		
1	dry	0.03	<0.01 - 0.06	7	0.37	<0.03 - 0.87	8	<0.03	<0.02 - 0.03	7
	wet	0.01	0.01 - 0.04	5	1.40	0.41 - 1.60	5	0.10	<0.02 - 0.10	5
2	dry	0.02	<0.01 - 0.04	7	0.27	0.12 - 1.30	8	<0.03	<0.02 - 0.03	7
	wet	0.01	<0.01 - 0.02	5	0.45	0.23 - 1.00	5	0.08	<0.02 - 0.15	5
4A	dry	0.02	0.01 - 0.05	7	0.11	0.09 - 0.20	8	<0.03	<0.02 - 0.02	7
	wet	0.01	<0.01 - 0.02	5	0.26	0.13 - 0.33	4	0.08	<0.02 - 0.10	5
4B	dry	0.02	0.01 - 0.02	7	0.10	0.01 - 0.28	8	<0.03	<0.02 - 0.09	7
	wet	0.05	0.01 - 0.02	2	0.30	0.05 - 0.56	2	-	<0.02 - 0.06	2
4C	dry	0.02	0.01 - 0.03	7	0.64	0.23 - 1.60	8	<0.03	<0.02 - 0.03	7
	wet	0.02	<0.01 - 0.03	2	0.33	0.28 - 0.38	2	-	<0.02 - 0.10	2
5	dry	0.01	<0.01 - 0.05	9	0.13	0.06 - 0.28	10	<0.02	<0.02 - 0.02	11
	wet	<0.01	<0.01 - 0.04	5	0.10	0.05 - 0.67	5	<0.02	<0.02 - 0.09	3

		NICKEL			TIN*			ZINC		
1	dry	<0.01	<0.01 - 0.04	7	<0.5	<0.5 2.7	7	0.06	0.01 - 0.10	7
	wet	0.02	<0.01 - 0.02	4	<0.005	<0.005 - 0.23	4	0.05	0.03 - 0.08	8
2	dry	<0.01	<0.01 - 0.05	7	<0.5	<0.5 - 0.5	7	0.05	0.02 - 0.06	7
	wet	0.03	<0.01 - 0.05	4	0.009	<0.005 - 0.076	5	0.04	0.02 - 0.08	8
4A	dry	<0.01	<0.01 - 0.01	7	<0.5	<0.5 - 0.5	7	0.04	0.01 - 0.10	7
	wet	0.04	0.02 - 0.05	3	0.018	<0.005 - 0.027	4	0.04	0.03 - 0.06	8
4B	dry	<0.01	<0.01 - 0.02	7	<0.5	<0.5 - 0.5	7	0.05	0.04 - 0.13	7
	wet	-	<0.01 - 0.02	2	<0.005	<0.005 - <0.005	2	0.08	0.06 - 0.11	4
4C	dry	<0.01	<0.01 - 0.03	7	<0.5	<0.5 - 1.5	7	0.09	0.05 - 0.15	7
	wet	0.03	0.02 - 0.03	2	<0.005	<0.005 - <0.005	2	0.09	0.07 - 0.15	4
5	dry	<0.01	<0.01 - 0.05	11	<0.5	<0.5 - 0.5	11	0.02	<0.01 - 0.12	11
	wet	<0.01	<0.01 - 0.03	3	<0.005	<0.005 - 0.005	4	0.05	0.01 - 0.08	3

(*) Wet weather tin values were measured using the furnace mode.

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Table 6-27: PERCENTAGE OF SAMPLES EXCEEDING 24 HOUR AVERAGE TOXICITY CRITERIA FOR METALS OF CONCERN

Station	1		2		4A		4B		4C	5		Lakewide
Weather Condition	wet	dry	wet	dry	wet	dry	wet	dry	total	wet	dry	total
copper	100	83	60	86	60	100	100	100	89	71	67	85
lead	100	29	75	43	75	14	50	29	33	33	27	40
zinc	50	57	38	57	29	29	100	86	100	40	30	52

Table 6-28: PERCENTAGE OF SAMPLES EXCEEDING MAXIMUM TOXICITY CRITERIA FOR METALS OF CONCERN

Station	1		2		4A		4B		4C	5		Lakewide
Weather Condition	wet	dry	wet	dry	wet	dry	wet	dry	total	wet	dry	total
aluminum	75	0	25	13	0	0	25	0	14	75	13	19
copper	40	71	20	86	20	86	50	50	77	25	44	53
iron	60	0	25	0	0	0	0	0	8	0	0	7
manganese	0	0	0	0	0	0	0	0	70	0	0	11

(outlet). Zinc exceeded the chronic criterion in all of the hypolimnion samples. Lead was the only one of the three metals that showed consistently higher violations during wet weather.

Direct aspiration detection limits for cadmium and chromium are higher than the 24 hour average criteria. Furnace results showed cadmium violations at all stations and potential chromium violations in the upper forebay and at the outlet. Chromium toxicity levels are listed by species (III or VI), but the analysis was on a total basis so it is not known what form it was in. However, since the toxicity level for chromium VI is so small, it is assumed that any chromium detectable in the Lake could present a threat to aquatic life. No 24 hour average criterion has been established for chromium III.

Literature Comparisons. Chronic toxicity levels found in the literature provide another basis for comparison since negative impacts of a specific metal on a specific species can be examined. A comparison of recorded concentrations with the chronic toxicity values for copper listed in Table 6-21 shows the following percent violations: brown trout, 13%; bluegills, 24%; rainbow trout, 53%; and catfish, 53%. Specific lead and zinc toxicity values for rainbow trout were not exceeded. The lead toxicity value for bluegills was exceeded in 7% of the samples. Again, it should be remembered that these values have actually been found to damage the particular fishery.

Maximum Toxicity Criteria. Table 6-28 summarizes the percentage of sample values that exceeded the maximum criteria during wet and dry weather sampling and lakewide. The metals in violation include aluminum, copper, iron, and manganese. Again cadmium and chromium are not included in the Table since they were in most cases not detected and the maximum criteria are at lower concentrations than their direct aspiration detection limits.

Copper was in violation most frequently and violations were fairly evenly distributed throughout the Lake with a greater percentage of dry weather samples in violation than wet weather. Aluminum and iron showed higher levels of violation during wet weather and most of the iron violations were in the upper forebay. Seventy percent of the hypolimnetic manganese samples exceeded the maximum criterion, this is a direct result of anoxic sediment release.

Cadmium, as detected by the direct aspiration mode, was only detected once (at the outlet) and violated the criterion at that time. Using the more precise furnace mode, however, cadmium exceeded the criterion at all stations. The same holds true for chromium. When using the furnace mode, potential chromium violations occurred in the upper forebay and at the outlet. Further investigation of cadmium and chromium in the Lake is needed.

Intermittent Exposure. The impact of urban runoff on lake systems should be considered both in terms of the load contributed to the system and elevated concentrations which may result. Given the nature of urban runoff, these elevated concentrations are often of short duration. EPA has proposed special criteria for estimating the effect of intermittent exposure for several metals as listed in Table 4-4. As would be expected, those exposure levels are higher than the 24 hour average and maximum criteria since the exposure time is assumed to be less.

As discussed earlier, aluminum, iron, lead, nickel and manganese showed elevated concentrations during wet weather. Intermittent exposure criteria are not available for aluminum, manganese, and iron so the 24 hour average and maximum criteria are the best available. Nickel did not exceed the more stringent 24 hour average and maximum criterion. None of the lead concentrations exceeded the intermittent exposure threshold level of 0.313 mg/l. This does not, however, mean that lead is not a problem since dry weather violations range from 27 to 43 percent across the stations. In conclusion, the limited intermittent exposure criteria which have been proposed are not particulary applicable to this evaluation.

Summary of Metal Toxicity to Aquatic Life. Aluminum, cadmium, chromium (VI), copper, iron, and manganese exceeded the maximum toxicity criteria for aquatic life calculated for Upper Mystic Lake. This means that these metals, under various weather conditions, are potentially an acute toxicity threat to aquatic life. Aluminum and iron are of particular concern during wet weather.

Copper, lead, cadmium, and zinc exceeded the 24 hour average or chronic criteria for the protection of aquatic life in Upper Mystic Lake under various weather conditions. Chronic toxicity levels for aluminum, arsenic, iron, manganese, and tin have not been established. The concern was lakewide since the violations are not located in just one area of the Lake. In addition, some of these metals may be toxic at lower concentrations when in the presence of other metals. For example, cadmium-zinc and zinc-copper combinations show the effects of synergism. Literature which clearly defines the toxic level of these synergistic metals could not be found. Appendix C discusses some of these synergistic effects. Literature values for acute and chronic toxicity indicate that only tolerant aquatic organisms will be able to exist in the Lake given the ambient water quality results. Overall, those results indicate a threat to a well balanced aquatic community. However, bioassays specific to conditions in the Upper Mystic Lake should be conducted to determine actual toxicity.

Suitability of Fish for Human Consumption. Table 6-29 presents the metal concentrations detected in the fish flesh. No arsenic, tin, nickel or chromium was detected. Mercury and aluminum were detected in all the species.

There were several aberrations in the data. Metals were widely distributed and not isolated by fish class. However, large mouth bass did not show similar metal concentrations as chain pickerel, both of which prey on golden shiners, bluegills, and alewives. Secondly, yellow perch is an omnivore and should have consumed some of each metal, yet only five were detected. These abnormalities may have been due to limited sample size (Bergin, 1981).

In terms of suitability for human consumption, the fish flesh samples were below the FDA standard of 1 ppm for mercury. This is the only metal standard available.

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Table 6-28. UPPER MYSTIC LAKE FISH FLESH METAL CONCENTRATIONS
(mg/kg)

	Aluminum	Arsenic	Cadmium	Chromium	Copper	Lead	Nickel	Mercury	Tin	Zinc
Large Mouth Bass	5	0.00	0.36	0.00	0.7	1.0	0.00	0.167	<0.50	6
Chain Pickerel	25	0.00	1.00	0.00	1.0	1.5	0.00	0.170	<0.50	11
Black Crappie	5	0.00	0.36	0.00	0.7	1.5	0.00	0.148	<0.50	14
Yellow Perch	6	0.00	0.00	0.00	0.0	0.0	0.00	0.136	<0.50	9
Blue Gills	40	0.00	0.00	0.00	1.0	1.1	0.00	0.0083	<0.50	12
Brown Bullheads	26	0.00	0.40	0.00	1.5	4.0	0.00	0.0005	<0.50	17
White Suckers	7	0.00	0.00	0.00	1.0	0.0	0.00	0.0513	<0.50	9
Carp	18	0.00	0.00	0.00	1.6	0.0	0.50	0.0253	<0.50	20
Alewives	6	0.00	1.00	0.00	2.0	7.0	0.00	0.175	<0.50	6
Goldenshiners	25	0.00	0.00	0.00	0.0	0.0	0.00	0.0513	<0.50	8
Sunfish	12	0.00	0.00	0.00	5.7	1.6	0.00	0.0717	<0.50	15
Mean Concentration	16	0.00	0.36	0.00	1.5	1.7	0.00	0.106	<0.50	11

California Water Quality Criteria prohibits a lead concentration greater than 7 mg/kg (McKee and Wolf, 1963). While Upper Mystic bullheads averaged below this limit, the lead content of this fish was considered high by the Massachusetts Division of Fisheries and Wildlife. They advised further study of the lead content by age/size classes, and until this analysis is completed eating bullheads from Upper Mystic Lake is not recommended. Otherwise, based on metals levels, they concluded that there is no immediate threat to human health(Bergin, 1981).

Table 4-5 presents ambient water quality criteria for the protection of human health from the toxic properties of metals ingested through contaminated aquatic organisms developed by EPA. Water quality data from the Lake were compared to this criteria. The results are as follows:

- All arsenic concentrations exceeded the criterion.
- The cadmium criterion is equal to its detection limit. Even though cadmium was detected at low levels in the Lake and exceeded the criterion only once, it should not be dismissed as an insignificant metal. Since it was detected in the fish flesh and is present in the Lake sediments (see Sediments Section), it is present in the lake system.
- Maximum wet weather lead concentrations exceeded or equaled the criterion.
- In-lake concentrations of chromium, copper, nickel, and zinc were below the criteria and do not present a problem for the protection of human health from eating aquatic organisms from the Lake.

In summary, arsenic, lead and possibly cadmium concentrations in the Lake exceeded the EPA criteria for the protection of human health from ingestion of contaminated organisms. As discussed earlier, these criteria are rough guidelines indicating a potential problem and more precise criteria are needed.

Comparison with Historic Conditions

Historic and recent in-stream metals data collected under other programs is summarized on Table 6-30. Compared with in-stream data collected under this study, concentrations of most of the metals have not changed significantly. An increase in manganese concentrations and a reduction in zinc levels seems to have occurred at the three stations examined. For some metals it was not possible to draw conclusions due to discrepancies between laboratory detection limits.

Limited historic metals data for the Lake has been collected from 1970 to 1980. Metals analyses included cadmium, total chromium, copper, iron, lead, manganese, mercury, selenium and zinc. Mercury and selenium were not analyzed in this study.

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TABLE 4-[illegible]: HISTORIC AND RECENT METALS DATA COLLECTED UNDER OTHER PROGRAMS (mg/l)

Metal and Date Sampled	Mishawum Road	Washington Street	USGS Gauge
Arsenic			
10/10/79	0.005	--	--
11/ 7/79	0.007	--	--
5/13/80	0.008	0.001	0.004
10/28/80	0.002	0.005	0.003
2/26/81	0.006	0.001	--
Cadmium			
10/10/79	0.005	--	--
11/ 7/79	0.005	--	--
5/13/80	*	*	*
2/26/81	*	*	--
7/28/81	0.03	*	*
Chromium			
10/10/79	0.005	--	--
11/ 7/79	0.005	--	--
5/13/80	*	*	*
10/28/80	*	*	*
2/26/81	0.03	*	--
7/28/81	0.03	--	--
Copper			
10/10/79	0.050	--	--
11/ 7/79	0.05	--	--
5/13/80	0.02	0.02	*
10/28/80	0.05	0.08	*
2/26/81	0.06	0.08	--
7/28/81	0.30	*	0.03
Iron			
6/ 2/70	--	--	1.50
4/25/73	5.0	2.1	0.90
10/10/79	0.53	--	--
11/ 7/79	0.6	--	--
5/13/80	1.1	2.0	0.65
10/28/80	1.5	1.1	1.0
2/26/81	1.6	1.9	--
7/28/81	1.2	1.7	1.0
Lead			
10/10/79	0.014	--	--
5/13/80	*	0.08	0.04
10/28/80	*	0.02	*
2/26/81	0.04	0.03	--
7/28/81	0.01	0.04	*
Manganese			
10/10/79	0.04	--	--
11/ 7/79	0.20	--	--
5/13/80	0.14	0.15	0.10
Nickel			
5/13/80	*	*	*
10/28/80	*	*	*
Zinc			
6/ 2/70	--	--	0.16
1/17/79	0.18	--	--
10/10/79	0.85	--	--
11/ 7/79	0.24	--	--
3/19/80	0.33	--	--
4/ 9/80	0.56	--	--
5/13/80	0.13	0.17	0.04
10/28/80	0.35	0.13	0.03
2/26/81	0.19	0.18	0.08
7/28/81	0.04	0.07	0.01

* Concentration Below Detection Limit

Sources: Jason M. Cortell, 1970.
Mass. WRC, 1974b.
Mass. MDC, 1980.
Mass. MDC, 1981.
Mass. DEQE, 1982d.

Of particular concern are the zinc concentrations recorded in 1970. In the spring of 1970, the Massachusetts Division of Fish and Wildlife attempted to stock the Lake with trout. When the fish were released through the ice, they immediately became distressed and died. Water quality samples were taken, and the conclusion was that the zinc present had killed the trout. The acute (maximum toxicity) criteria for zinc is 0.27 mg/l and their results recorded a level of 0.5 mg/l, which also exceeds the specific level for trout.

Two months later, Jason M. Cortell and Associates (1970) recorded a level of 0.06 mg/l zinc at Sandy Beach which is considerably less than that found by the Division but does exceed the 24 hour average chronic criteria. A bioassay was run using Lake water and it was found to be non-toxic to fish in a 48 hour test. High chlorides and ammonia concentrations (see Nitrogen Section) were also suspected of killing the fish in March but more likely it was a combination of factors.

First, the fish may have experienced a temperature shock as they were let loose through the ice. This would have killed them within minutes. Secondly, a lack of dissolved oxygen at the temperature (and depth) at which trout must live may have added enough stress to kill them. Since the Lake was under ice, the chances of an oxygen deficit at this time seems likely. Zinc also lowers oxygen absorption capability so they may eventually suffocate. Although the zinc and chlorides may have been at toxic concentrations, it is doubtful that the concentrations present would have killed the fish instantly.

In 1975, zinc was measured in the Lake and Inlets by the DEQE Division of Water Pollution Control (DWPC). Epilimnetic, hypolimnetic and outlet samples exceeded the 24 hour average criterion. In fact, the concentration in the hypolimnion at this time was very close to the acute toxicity level. Lakewide, zinc measurements taken in 1978 by the DWPC also exceeded the chronic toxicity level and hypolimnetic values exceeded the acute level. However, in 1980, zinc concentrations were below the toxic level.

Cadmium was detected in the lake in 1978 at levels which exceeded the maximum toxicity criterion. Chromim was also detected at this time and exceeded the 24 hour average toxicity criterion for chromium (VI). These concentrations are similar to the current levels detected by the furnace method in this study.

Copper was detected in the lake in 1970-71 at levels that exceed both maximum and 24 hour average toxicity criteria. Values ranged from 0.03 to 0.09 mg/l which is higher than present levels in the Lake, Aberjona inlet, and Lake outlet. Copper was not deected in samples taken in 1980.

Iron concentrations were measured from 1974 to 1980. The maximum criterion was exceeded at the Aberjona inlet and in the hypolimnion. This is also the current situation in the lake. Iron values monitored over the years are comparable to values found presently.

Lead concentrations were measured in 1978 and 1980. All the samples exceeded the 24 hour average toxicity level. Manganese concentrations never exceeded any toxic criteria and wer within the ranges of current levels.

6.7 COLIFORM BACTERIA

Controlling Conditions and Water Quality Significance

The various species of coliform bacteria are ubiquitous in nature, but are most commonly found in soils and domestic wastewaters. For water quality purposes, coliforms have been grouped into two categories: total and fecal. The total coliform group includes all species of coliform, whereas the fecal types are only those found in human and warm-blooded animal wastes.

Both groups of coliform are used as an indicator of disease-causing organisms and parasites present in water. There are numerous species of pathogenic bacteria, viruses, protozoa, and parasitic worms found in domestic wastewater, making comprehensive analysis of the types present complex and time consuming. Coliform bacteria are used to indicate contamination since they are always present in fecal waste in greater numbers than the other disease-producing organisms, generally survive for longer periods, and are not pathogenic.

Coliform are not able to survive for extended periods or reproduce in aquatic environments. Survival times depend on a variety of physical and chemical factors including: temperature, pH, and dissolved oxygen content. In general, total coliform can survive longer than fecal.

Several standards have been established for both total and fecal coliform in drinking waters and waters used for swimming. Since the Upper Mystic Lake is not used for drinking, only bathing standards, as discussed in Chapter 4.0, are of interest here. Fecal coliform is considered a better indicator of pathogen presence. The actual closing of or posting of warning signs at a bathing facility is at the discretion of local boards of health, the State Department of Public Health, and in the case of MDC beaches, the MDC.

Existing Conditions - In-stream

A summary of in-stream total and fecal coliform data can be found on Table 6-31. In only two instances were the median concentrations for either type of bacteria below the 200 fecal coliform/100 ml standard for Class B fishable/swimmable waters. These were the fecal coliform values at Mill Street and the West Shore Inlet for dry and wet weather, respectively. As discussed earlier, sewage contamination was evident in Sweetwater Brook from combined manhole overflows and elevated coliform concentrations in Sweetwater Brook as well as downstream of its confluence with the Aberjona, Washington Street and USGS, are attributable to that source. Sewage contamination is also suspected in the Boat Club Inlet. It should also be noted that while coliform levels at Mishawum Road and Mill Street were generally less than those downstream, they too were high especially during wet weather. Coliform levels in urban runoff have been shown to vary significantly and the values recorded at these two stations are within the range of literature values.

Table 6-31: SUMMARY OF INSTREAM COLIFORM CONCENTRATIONS

Station	No. Samples	Total Coliform (Coliform/100 ml)					Fecal Coliform (Coliform/100 ml)					No Samples
		Means*	Median	Range			Means**	Median	Range			
[illegible] Rd.												
Wet	13	39,000	17,600	1,500	-	200,000	3,180*	1,700	2	-	12,000	13
Dry	5	3,300	1,800	400	-	9,000	360	150	100	-	1,200	5
Mill St.												
Wet	15	42,955	4,200	1,200	-	300,000	5,200*	1,000	2	-	32,000	15
Dry	3	2,300	1,300	680	-	5,000	120	90	80	-	180	3
Washington St.												
Wet	11	121,000	65,000	10,000	-	440,000	13,400*	4,600	24	-	41,000	11
Dry	5	86,700	20,000	13,300	-	320,000	11,300	4,700	2,400	-	40,000	5
USGS Gauge												
Wet	11	58,364	50,000	15,000	-	160,000	7,800	4,000	56	-	30,000	11
Dry	7	4,600	1,400	700	-	15,000	900	220	20	-	3,400	7
Sweetwater Brook												
Wet	16	5,073,373*	1,750,000	940	-	21,200,000	178,200*	7,000	100	-	1,310,000	16
Dry	6	1,365,000	134,500	20,000	-	3,000,000	170,200	155,000	2,200	-	400,000	6
Boat Club Inlet												
Wet	4	45,220	40,000	6,100	-	90,000	4,500	4,000	1,100	-	10,300	4
Dry	9	68,600	9,000	300	-	409,000	15,000	800	60	-	90,000	9
West Shore Inlet												
Wet	4	2,467	1,800	1,200	-	4,400	90*	20	10	-	240	4
Dry	9	2,100	1,700	180	-	3,800	280	220	47	-	800	9

** Means were rounded off.
* Some values within the range were reported as less than or greater than.

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Existing Condition - In-lake

There are several areas in the Lake which are of particular concern in regard to total and fecal coliform contamination. These include the two forebays, Sandy Beach and the Lake outlet. Table 6-32 presents coliform data collected lakewide. Fecal coliform levels above the 200 coliform/100 ml were found in approximately one-third of the samples tested in the upper and lower forebays and occassionally near the Lake outlet.

Of special concern is the impact of the Aberjona River coliform loadings on Sandy Beach. The flow of the Aberjona greatly influences the retention time in the forebays (as discussed in Chapter 2.0). Under low dry weather flows, the forebays act as detention ponds, offering quiescent conditions, diluting capabilities and opportunity for coliform die-off. Under wet weather conditions, with higher Aberjona flows, the retention time in the forebays is shortened to less than two days which, given the survival rate of coliform in an aquatic system, could impact Sandy Beach. Also, as seen in the circulation studies, water flowing from the lower forebay into the main basin can be held in the northern part of the main basin (see Figure 2-4). If such water contained high coliform counts, this would impact Sancy Beach. In addition, Sandy Beach exceeded the MDC coliform standard in July 1982 and warnings that swimming could be hazardous to public health were posted for several days.

As discussed in Chapter 5.0, studies have pointed to several areas where sewage is entering surface waters. Most comes from the combined manhole overflows to Sweetwater Brook, but six areas in Winchester's sewer line also occasionally surcharge. Two of these sites discharge directly to the Lake. Inadequate capacity in the sewer line located along Route 3 causes overflows to the stormwater line which drains to the lower forebay. Samples collected from the Route 3 stormwater outfall during wet and dry weather reflected this problem. Additionally a stormwater outfall between the two forebays is used as a relief line for the inverted siphon in the sewer line which runs under the Lake. Two other areas of concern were indicated from test results. Elevated bacteria levels were found in the Boat Club Inlet and at the Lake outlet, but the sources of contamination were not identified and need further investigation.

Comparison with Historic Conditions

Historic in-stream data collected by DWPC and MDC is shown on Table 6-33. Comparing these means to data collected for this project indicates that coliform levels have not changed significantly in most cases. Some fluctuations are expected due to dry and wet weather differences. Levels of fecal coliform at Washington Street and both forms at the USGS Gauge have increased however, possibly due to worsening conditions in Sweetwater Brook.

Historic in-lake coliform data (1973-1979) collected by DWPC and MDC at Sandy Beach and the Lake outlet were generally within the range of coliform concentrations observed during this study. Current maximum total coliform values were significantly higher than historic maximum values.

TABLE 6-32: SUMMARY OF INLAKE COLIFORM CONCENTRATIONS: RAW DATA
(coliform/100ml)*

DATE	UPPER FOREBAY		LOWER FOREBAY		SANDY BEACH		OUTLET	
	TOTAL	FECAL	TOTAL	FECAL	TOTAL	FECAL	TOTAL	FECAL
6/5/81							1000	100
6/25					1200	110		
7/13	200	100	32	<10	24	<10	4	<10
	300	12	400	<10			300	20
	400	12						
	200	<10						
	600	< 8						
	700	8						
7/28	160	10	200	< 5			100	<5
8/6	3000	10	600	8	300	12	500	<10
8/7	3000	50	450	<10	80	2	10	2
8/8	20,000	0	30,000	<10	800	<10	15	6
8/20	120	< 5	180	20			20	<5
8/25	1200	900	1100	500	100	32	10,000	1400
	800	800	1300	600				
	800	200	300	300	1400	300		
	800	220						
8/26	100	14	5000	800	600	88	90	40
	100	<10	5000	800	66	42		
8/27	100	5	200	200	1500	10	700	440
9/16	2900	<10	6100	40	< 10	<10	<10	<10
9/17	1600	170	1600	330	3800	20	370	<10
9/19	10,000	6600						
	720	720						
	840	800						

* Based on DEQE Data

TABLE: 6-33: HISTORIC TOTAL AND FECAL COLIFORM MEANS*
(coliform/100 ml)

	Mishawum Road		Washington Street		USGS Gauge	
Year	Total	Fecal	Total	Fecal	Total	Fecal
1967	-	-	42,500	-	21,100	-
1973	15,100	-	26,900	-	12,500	-
1975	-	-	-	-	3,700	-
1976	-	-	-	-	3,400	-
1977	-	-	-	-	300	-
1978	189,500	13,000	58,000	19,500	1,600	30
1979	4,100	400	103,000	25,300	2,800	217
1980	1,900	400	72,000	3,000	8,400	1,100

* Means calculated using data collected from May through September, and are rounded-off to nearest hundred.

Sources: Mass. DEQE, 1981c, 1982d; Mass. MDC, 1977, 1978,1979a;
Mass. WRC, 1974a, 1974b.

6.8 SEDIMENTS

Controlling Conditions and Water Quality Significance in Lake Systems

Sediments are composed of particulate mineral matter from geologic, meteorologic and hydrologic sources; organic matter in various stages of decomposition; inorganic constituents such as calcium carbonate and silica; and water. Urbanization and industrial activity can severely alter the natural composition of sediments through waste disposal and runoff which can deposit metals, synthetic organic chemicals and other constituents.

Sediments play an important role in the biological, chemical and physical cycles of a lake. They can act as a depository or sink for organic and inorganic matter entering the lake, or under certain conditions can release certain constituents. Sediments high in organic content can place a significant oxygen demand on the overlying waters, and also tend to have higher metal concentrations than unpolluted sediments.

Under oxygenated conditions, certain metals and nutrients remain in an insoluble, relatively unreactive form and remain bound to the sediments. However, under anoxic conditions, microbiological activity and chemical reduction can release metals and nutrients to the water column that would otherwise be locked up. Sediments can also exert a significant oxygen demand. The sediments also provide a niche for bacteria, macroinvertebrates, fish and plants. If the sediments contain significant metal levels, they themselves may be toxic to bottom dwelling aquatic life. Lastly, sediments can act as thermal mass, gaining or loosing heat to the overlying waters.

The form in which metals enter the sediment phase is particularly important since it will determine the availability, rate and extent to which redistribution and recycling occurs. Metals present in the crystalline structure of the sediments are considered unavailable and relatively inert. Metals associated with organic matter or metal oxides require either chemical changes or bacterial respiration to release them; hence, they are less available. Metals in an ionic form at the sediment/water interface are readily available.

High nutrient levels in lake sediments are not uncommon. Decaying matter, suspended solids and wastes settle to the lake bottom, decompose and increase the nutrient concentrations of the bottom muds. Aluminum, calcium, manganese and iron under certain conditions form an insoluble compound with phosphorus and settle out.

There are no state or federal standards for defining lake sediment quality characteristics. There are, though, several rough guidelines and ranking systems available. Two ranking systems were used in this analysis: the Great Lakes Rating Criteria and the Sediment Pollution Index as described in Section 3.3. In addition, Upper Mystic sediment data was also compared to sediment data from sixteen other Massachusetts lakes.

Existing Conditions - Upper Mystic Lake

Table 6-34 presents sediment data for Upper Mystic Lake. Metals are listed in order of decreasing mean concentration, with nutrients listed at the bottom. Due to their natural abundance in soils, iron, aluminum, and manganese were expected to have greater concentrations than other metals.

The upper forebay had the highest concentrations of magnesium, zinc, lead, chromium, copper and mercury. These metals are associated with organic matter and particulates; thus they would settle out quickly upon entering the Lake. Copper concentrations are highest in the forebays which may, in part, be due to copper sulfate treatments for algae control. According to the MDC (DiPietro, 1982), copper sulfate was used in the 1960s and 1970s with localized applications in the forebays and at selected sites along the main basin shoreline. Iron, manganese, and aluminum concentrations were highest in the main basin. Cadmium, arsenic, nickel and tin concentrations were fairly evenly distributed at all sites.

Great Lakes Sediment Criteria. Table 6-35 summarizes the results of this ranking procedure for the lake sediments. The concentrations of lead, zinc, nickel, arsenic, cadmium, chromium, copper, mercury (except at the deep site) and iron (except at the mouth of the Aberjona) all ranked as heavily polluted. Total kjeldahl nitrogen ranked as moderately polluted at all sites. Manganese concentrations ranked as heavily polluted at the deep site and moderately polluted at all other sites. The deep site is also where hypolimnetic manganese exceeded the maximum toxicity criteria for the protection of aquatic life. Nickel was the only metal that ranked as non-polluted at all sites; phosphorus concentrations ranked as non-polluted at all the sites except in the main basin where it ranked as heavily polluted.

Comparison of Sediment Data to Other Lakes. Upper Mystic Lake sediment data was compared to the following Massachusetts lakes and ponds: Attitash, Indian, Pontoosac, Waushakam, White Island, Mattawa, Norton, Winthrop, Eagle, Boon, Fort, Wyman, East Lake Waushakam, Whitman, Cedar, and Quinsigamond (McGinn, 1982). These lakes range in characteristics from eutrophic to oligotrophic, urban to rural, deep to shallow. Table 6-36 presents the results of this comparison. Of particular concern are the arsenic, chromium, lead, copper and zinc concentrations. Upper Mystic mean concentrations of these metals are above the maximum concentrations of the other lakes. The maximum arsenic concentration in the other lakes was less than half that found in Upper Mystic Lake.

Cadmium, iron and aluminum concentrations fell in the range of the other lakes, but the mean Upper Mystic concentrations exceeded the means of the other lakes. The iron concentration at the deep site in Upper Mystic was double the mean of the other lakes. Nickel was the only Upper Mystic mean concentration lower than that for the other lakes.

Clarke Number (CN) Comparisons and Sediment Pollution Index (SPI). Table 6-37 summarizes the results of the CN comparisons and SPI. Aluminum was not included because of its relative natural abundance.

Table 6-34: METAL AND NUTRIENT VALUES OF UPPER MYSTIC LAKE SEDIMENTS

Metal (mg/kg) Dry Weight	Mouth of Aberjona	Upper Forebay	Lower Forebay	Deep Site Main Basin	Mean
Iron	22,404	37,646	32,375	53,097	36,380
Aluminum	11,546	19,813	18,008	22,418	17,946
Magnesium	3,619	5,151	4,856	3,736	4,341
Zinc	1,395	2,972	2,631	2,753	2,438
Lead	982	1,149	890	885	977
Manganese	396	416	405	983	550
Chromium	224	951	566	256	499
Copper	345	535	465	433	445
Arsenic	110	87	138	157	123
Nickel	29	46	42	47	41
Cadmium	8.6	14	12	9.8	11
Tin	6.9	3.9	2.0	1.9	3.7
Mercury	1.72	2.37	1.45	0.63	1.54
TKN	2,800	6,660	6,170	5,960	5,470
Total P	666.5	222.5	412.5	275.5	394.3

Table 6-35: RESULTS OF GREAT LAKES SEDIMENT RATING CRITERIA FOR UPPER MYSTIC LAKE

Parameter	Non-Polluted	Moderately Polluted	Heavily Polluted
TKN		M, U, L, D	
Lead			M, U, L, D
Zinc			M, U, L, D
Iron		M	U, L, D
Nickel	M, U, L, D		
Manganese		M, U, L	D
Arsenic			M, U, L, D
Cadmium			M, U, L, D
Chromium			M, U, L, D
Copper			M, U, L, D
Mercury		D	M, U, L
Total Phosphorus	U, L, D		M

Station Identification:
(M) = Mouth of Aberjona River
(U) = Center of Upper Forebay
(L) = Center of Lower Forebay
(D) = Deepest site in Main Basin, Station [illegible]

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Pollution free sediments are expected to contain metal concentrations less than or equal to those given by the CN. The ratio of the sediment concentration to the Clarke Number indicates the degree of contamination. Uncontaminated conditions would generally have a ratio of less than one or two. In Upper Mystic Lake this is the case with nickel, iron and manganese. As can also be seen in the water quality data, nickel was not a metal of concern. The CN comparisons for iron and manganese equalled one. In comparison with the other values on Table 6-37, these results look insignificant. In comparison with CNs from other Massachusetts lakes, however, Upper Mystic iron and manganese sediment concentrations in the main basin are extremely high (Mass. DEQE, 1981b).

Sediments containing higher metal concentrations than those indicated by the CN may be polluted. This is the case for arsenic, cadmium, lead, mercury, and zinc in the Lake. Chromium and copper are close to their CNs, but in comparison to the CN in other Massachusetts lakes where they rarely exceeded 1, the Mystic CN comparisons for copper and chromium indicate contamination.

Table 6-37 also shows the Sediment Pollution Index calculated for each of the four sites and Lake average concentrations. For 15 other Massachusetts lakes, the SPIs ranged from 1.8 to 27.0 with a mean of 8.2. For Lake Quinsigamond, another urban lake, the SPI ranged from 12.9 to 27.8 with a mean of 20. The SPI range for Upper Mystic Lake indicate a higher degree of metal contamination. The upper forebay had a slightly higher SPI than the other sites but considering the overall degree of contamination in the Lake, this is not very significant.

Comparison with Historic Conditions. Sediment data from the deep site collected in 1981 were compared to surface sediment data collected in 1974 by the Division of Water Pollution Control as shown on Table 6-38 (Mass. DEQE, 1975). Unfortunately, historic data only exist for four parameters and only one sample was collected in 1974. Sampling techniques were the same for both data sets.

As can be seen, there has been a dramatic change in the sediment composition over the last seven years. TKN concentrations have decreased significantly. This drop in organic nitrogen is also reflected in the water quality data. Iron and manganese concentrations increased significantly, a factor of 10 for manganese and a factor of 4 for iron. Current phosphorus concentrations are double those of 1974. This increase is reflected in hypolimnetic water quality.

Table 6-36: COMPARISON OF UPPER MYSTIC LAKE SEDIMENT DATA TO SIXTEEN MASSACHUSETTS LAKE'S SEDIMENT

Metal (mg/kg) dry wt.	Range of Other Lakes	Mean of Other Lakes	Mean of Upper Mystic
Aluminum	5,377 - 25,300	17,075	17,946
Arsenic	.7 - 43	14.1	123
Cadmium	0 - 7.1	2.6	11
Chromium	5 - 150	36	499
Copper	20 - 940	284	445
Iron	6,200 - 88,200	28,843	36,380
Lead	72 - 970	274	977
Nickel	20 - 201	56	41
Zinc	80 - 863	279	2,438
Mercury	.12 - .60	.23	1.54

Table 6-37: CLARKE NUMBER COMPARISONS AND SEDIMENT POLLUTION INDEX RESULTS

	Mouth of Aberjona	Upper Forebay	Lower Forebay	Main Basin	Average Lake Conc.
Arsenic	61	48	77	87	68
Cadmium	43	70	60	48	53
Chromium	2	9	5	3	5
Copper	6	13	8	8	8
Iron	.4	.7	.6	1.0	.6
Lead	78	92	71	71	78
Nickel	.4	.6	.6	.6	.6
Manganese	.4	.4	.4	1.0	.5
Mercury	21	39	18	8	19
Zinc	23	42	28	26	27
SPI	26	34	31	30	30

Table 6-38: COMPARISON OF 1974 to 1981 SEDIMENT DATA (mg/kg) dry weight

	1974	1981
Total Kjeldahl Nitrogen	12,000	5,960
Total Phosphate - P	150	280
Manganese	90	980
Iron	12,000	53,100

6.9 SPECIAL LAKE CONSIDERATIONS

This section will discuss the water quality significance, existing conditions and historic comparison for pH, alkalinity, acidity, chlorides, hardness, specific conductance and transparency.

pH, Alkalinity, and Acidity

Water Quality Significance. The pH of a solution is a measure of its hydrogen ion activity and is expressed as the logarithm of the reciprocal of the hydrogen ion concentration. Since pH is expressed as a logarithm, it is important to remember that a change of one pH unit represents a ten-fold change in hydrogen ion concentration; for example a pH of 6.0 has ten times the hydrogen ions of pH 7.0. The pH scale extends from 0, very acidic, to 14, very alkaline with the middle value, 7.0 corresponding to exact neutrality.

The Massachusetts Water Quality Standard for Class B waters states that pH shall be in the range of 6.5 to 8.0 standard units. Most natural waters fall within the range, 6.0 to 8.0 (Lind, 1979). The majority of waters are slightly basic due to the presence of carbonate and bicarbonate. A departure from the norm could be caused by the entry of strongly acidic or basic wastes, inputs of carbon dioxide, hydrogen sulfide or ammonia nitrogen. Changes in pH may signify biological activity. Algal photosynthesis removes carbonate from the water, commonly raising surface pH levels to 9 or 10.

Lowered pH contributes to the solubility of metals. The impact of acid precipitation on metal availability is an example. As acid rain drenches the soils and paved surfaces, it helps to dissolve the metals, thus releasing them in a readily available (ionic) form to stormwater systems and receiving waters. Once in the aquatic system though, the pH is slightly less acidic causing the metals to bind to suspended material. Acid precipitation may in effect clean the streets and soils of metals, but it can also have several damaging impacts: soils depleted of metals leave plants without their essential nutrient requirements; receiving waters may become laden with metals which can be toxic to aquatic life; and the overall pH of the aquatic system can be lowered. Extreme pH levels affect the metabolic processes of various fauna: fish and aquatic insects lose their ability to absorb oxygen from the water.

A lake's ability to counteract changes in pH is called its carbonate buffering capacity. Buffering capacity is the total reserve of alkalinity and acidity in the water. The alkalinity of water is its capacity to accept protons or nuetralize acids. The three components of alkalinity include: hydroxide (OH^-); carbonate ($CO_3^=$); and bicarbonate (HCO_3^-). All three are summed as total alkalinity. Alkalinity in waters is generally the result of bicarbonates, but is expressed in terms of calcium carbonate. Total alkalinity in natural waters ranges from 20 to 200 mg/l.

Acidity, on the other hand, is the capacity of water to donate protons. There are three sources of acidity: dissolved carbon dioxide from plants and the atmosphere; acidity from wastewaters caused by dissolved minerals; and acid precipitation. An equilibrium between carbonate, bicarbonate and carbon dioxide exists in natural waters. It is this equilibrium, or balance of protons, that determines a lake's buffering capacity.

Existing Conditions. The pH levels in the surface waters of the Lake ranged from 6.5 to 9.2. The slightly lower values (less than 7.0) were observed in the forebays following storms and constantly in the hypolimnion. High pH values of 8.9 to 9.2 were recorded after hot dry spells in the surface waters of the Lake. These high values were shortlived and are common to lakes with high levels of productivity. Overall, the pH levels recorded are within the expected ranges. Inlet pH values ranged from 4.8 to 7.1. The low value of 4.8 was observed on the West Shore Inlet during a heavy rain storm.

In-lake alkalinity levels ranged from 19 to 41 mg/l with a mean of 38 mg/l. Based on these alkalinity values, the Lake seems to have an adequate buffering capacity. Inlet aklalinity levels ranged from 2 to 30 mg/l with a mean of 22 mg/l. The low value of 2 mg/l was recorded at the West Shore Inlet during a heavy rain storm.

Historic Comparison. Alkalinity levels recorded did not deviate from previous levels. During a summer hot spell a maximum pH of 10.2 was recorded in 1974 (Mass. DEQE, 1975). In 1974, Massachusetts DEQE (1975) concluded that the Lake was adequately buffered.

Chlorides

Water Quality Significance. Chloride, in the form of Cl^-, is a major inorganic anion found in lakes. The concentration of chlorides in surface waters varies widely ranging from trace amounts to several hundred mg/l. Seawater chloride concentrations are between 18,000 and 19,000 mg/l. Wastewaters and runoff contain higher chloride levels than receiving waters because sodium chloride is a common part of the human diet and is generally the major component in road salt. Concentrations of chlorides are of little health concern except at extremely high levels (Lind, 1979).

Existing Conditions. Chloride concentrations in Upper Mystic Lake ranged from 37 to 85 mg/l, with a mean of 68 mg/l. Upper Mystic Lake does not have a chloride problem at this time. Inlet concentrations ranged from 21 to 88 mg/l.

Historic Comparison. Chloride levels currently in the Lake are much lower than previously recorded. In 1970, surface and hypolimnetic values reached 155 mg/l which is near the toxic level for trout (Jason M. Cortell, 1970). Chloride concentrations in 1974 in the Lake ranged from 100 to 190 mg/l. The inlet concentrations in 1970 and 1974 were much higher than current levels. In February 1974, Boat Club Inlet values reached 1,040 mg/l -- 10 times higher than current levels. This February value may have been due to road salting.

Hardness

Water Quality Significance. Hardness is the measure of divalent metallic cations such as calcium, magnesium, ferrous iron, and manganous ions, and is expressed as calcium carbonate ($CaCO_3$). Hardness is important because it affects the tolerance of certain fishes to toxic metals (Lind, 1979). The hardness of water falls into the following classifications:

0 - 60 mg -$CaCO_3$/l - soft,
61 - 120 mg -$CaCO_3$/l - moderately hard,
121 - 180 mg -$CaCO_3$/l - hard, and
181 mg -$CaCO_3$/l & above - very hard (Lind, 1979).

Existing Conditions. Upper Mystic Lake is a moderately hard Lake with a range of hardness values of 61 to 90 mg -$CaCO_3$/l. The Lake mean value was 80 mg -$CaCO_3$/l. This value was used in the metal toxicity calculations for the Lake.

Historic Comparison. These values do not deviate significantly from levels found in 1974.

Specific Conductance

Water Quality Significance. Specific conductivity is the measure of water's capacity to convey an electric current. It is an indirect measure of the total concentration of dissolved ionic matter in the water such as salts, nutrients, and metals. Most natural waters range in specific conductivity from 50 to 500 umhos. Industrial wastes can be in excess of 10,000 umhos.

Existing Conditions. The specific conductivity levels in Upper Mystic Lake and its inlets ranged from 270 to 570 umhos, with a mean of 384 umhos.

Historic Comparison. Specific conductivity levels in 1974 were much higher than current levels, ranging at the deep hole from 500 to 600 umhos. Inlet values were also higher reaching 2,900 umhos at the Boat Club Inlet (February 1975) and 1,160 umhos at the West Shore Inlet (February 1975) (Mass. DEQE, 1975).

Transparency

Water Quality Significance. Transparency is a measure of the depth to which one can see into the water. It is measured by a Secchi disk. Water clarity is important in terms of recreation as well as the health of aquatic organisms and plant productivity. Low visibility can indicate poor water quality. Low visibility may be due to factors such as turbidity and solids loadings from external sources to the lake, excessive turbulence keeping the sediments in suspension, or excessive plankton growth clouding the water column. The Massachusetts Class B Standard for turbidity is a minimum Secchi disk transparency of 4.0 feet.

Existing Conditions. Table 6-39 summarizes the Secchi disk readings taken during this study. Overall, the readings at all the stations were very shallow. The low readings were probably due to excessive algal growth in the water column, suspended solids and color from all the organic materials

Table 6-39: SUMMARY OF SECCHI DISK READINGS
(Feet)

DATE	Center of Upper Forebay (A)	Center of Lower Forebay (B)	Main Basin (4)	Outlet - 10 feet from dam
12/9/80	3.0	---	7.0	---
6/23/81	3.0	---	5.0	---
6/25/81	2.5	2.6	5.5	10.3
7/13/81	2.5	2.5	5.0	4.3
7/28/81	2.0	1.3	2.0	---
8/6/81	1.7	1.7	2.0	1.7
8/7/81	2.0	2.0	1.7	1.9
8/8/81	2.8	2.7	2.7	2.4
8/20/81	2.5	3.0	3.5	4.0
8/25/81	1.7	2.2	3.9	3.5
8/26/81	2.0	2.5	3.9	3.7
8/27/81	1.7	2.5	3.5	3.5
9/16/81	1.9	2.2	3.6	3.9
9/17/81	2.0	2.0	4.6	4.9
9/19/81	2.5	2.9	5.6	3.9
9/28/81	4.0	4.0	9.0	---
10/14/81	3.9	3.6	7.2	---
11/12/81	3.2	3.9	5.9	6.6
5/21/82	5.0	5.0	8.0	8.0

in the Lake. In fact, the productivity of the algae population in the Lake may be inhibited to some degree by low light penetration. This is hard to quantify.

In terms of the Massachusetts turbidity standard, 89% of the readings in the two forebays and 47% of the readings in the middle of the main basin violated the standard. These percentages are extremely high. Even the outlet had poor water transparency. The readings taken during and directly following storm events were not significantly shallower than during dry weather conditions. As expected, deeper readings occur in the autumn months when there is not as much algae in the water column.

Comparison to Historic Conditions. The Secchi disk readings taken during the 1974 DWPC Lake survey are as shallow as the current readings. Readings were taken for the main basin only. In 1974, the only violation of the Massachusetts standard in the main basin occurred in August. During this study, the violations in the main basin also occurred during August, but violations in the forebays occurred year round.

6.10 AQUATIC LIFE

Controlling Conditions and Water Quality Significance

The biotic community, or biota, consists of all the plants and animals in a given area. In aquatic systems, chemical, physical and biological factors control the size and diversity of the biotic community present.

Physical and chemical influences include: temperature, light, water movement, nutrient availability, dissolved oxygen concentrations, and the presence of toxins such as ammonia-nitrogen and metals. Specific impacts related to these conditions are described in the appropriate sections of this chapter.

The existing food chain is a major biological control. Seasonal changes in certain organisms can result in a shift of other parts of the food chain. For instance, in the spring when green algae are at the peak of their growing cycle, certain species of zooplankton also increase. In some cases, manipulation of the food chain can be used to control certain organisms by introducing a predator of an undesirable species. This is discussed in more detail in Chapter 7.0.

A second biological control on the biota is the secretion of by-products from certain organisms. For example, bluegreen algae secrete endotoxins which are toxic to certain species of fish. Additionally, disease-causing organisms such as fungi, viruses and parasites can control populations. The appearance of such organisms is usually sporatic and can deplete or eliminate a target species very rapidly and sometimes permanently.

The existing biotic community can be used as an indicator of the water quality of an aquatic system. A community with low diversity (few species) is indicative of a stressed environment, whereas, one with a high diversity (many species) indicates a cleaner generally unstressed condition.

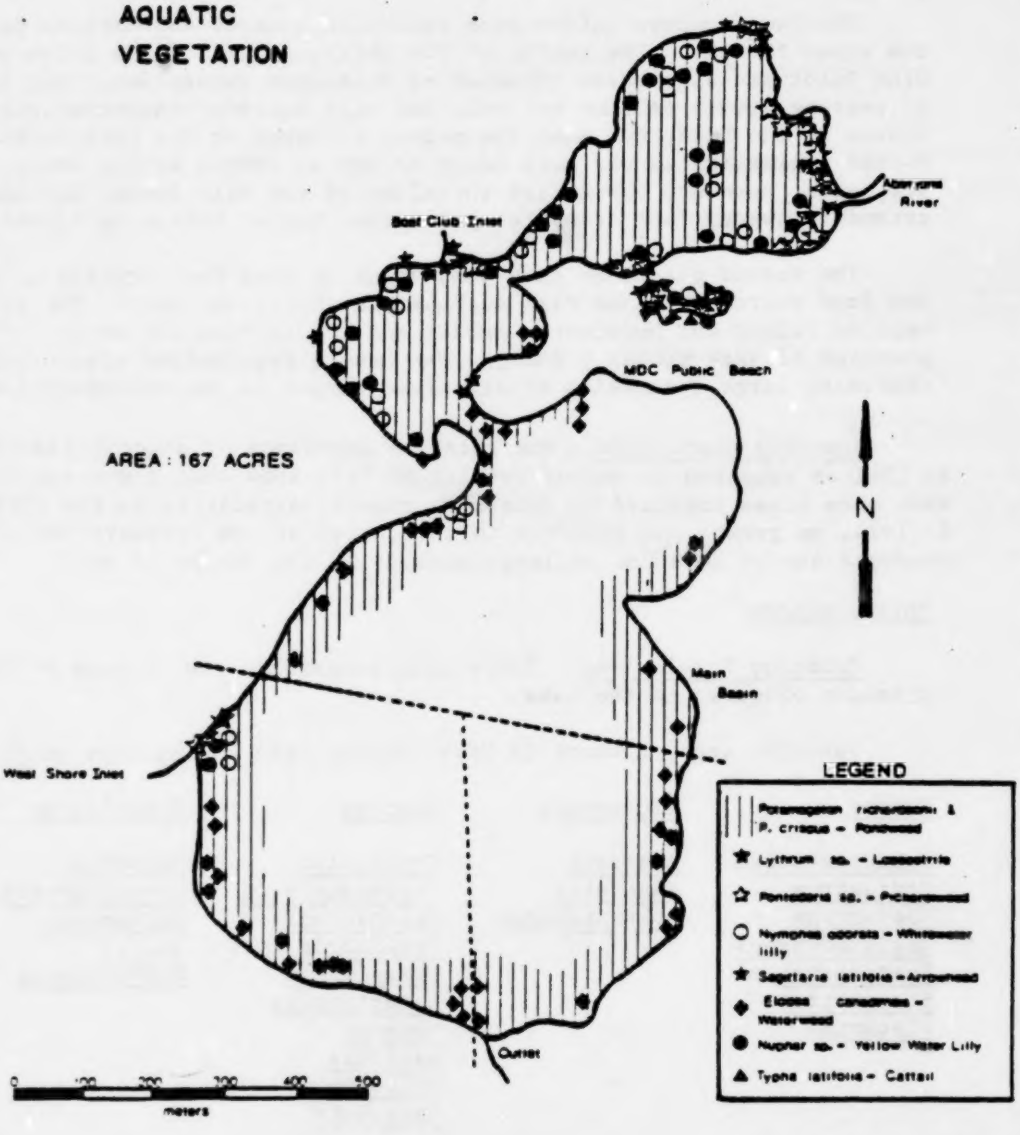
This section serves as baseline information on the fish, rooted aquatic plants, phytoplankton, and benthic macroinvertebrates identified during the study. In particular, the fish survey data were analyzed in terms of the distribution of species and age and growth rate comparisons. The latter can be used to indicate the overall health of the fish population in the Lake. The analyses result in a rating for each species called a Condition Factor based on the relationship of length to weight.

Rooted Aquatic Vegetation

Existing Populations. Figure 6-9 shows the distribution of rooted aquatic vegetation in Upper Mystic Lake. Vegetation was limited to the shallow areas and littoral zone of the Lake. The forebays were dominated by two species of Potamogeton (P. richardsonii and P. crispus) and two species of water lilies (Nymphea odorata and Nuphar sp.). The shoreline of main basin was dominated by Potamogeton (both species) and a form of waterweed (Elodea canadensis). Other species with limited distribution were: loosestrife (Lythrum sp.); pickerelweed (Pontederia sp.), arrowhead

UPPER MYSTIC LAKE

FIGURE 6-9:
AQUATIC
VEGETATION


Boat Club Inlet
Aberjona River
MDC Public Beach
AREA: 167 ACRES
N
Main Basin
West Shore Inlet
Outlet
0 100 200 300 400 500
meters
LEGEND
Potamogeton richardsonii & P. crispus – Pondweed
Lythrum sp. – Loosestrife
Pontederia sp. – Pickerelweed
Nymphaea odorata – Whitewater lilly
Sagittaria latifolia – Arrowhead
Elodea canadensis – Waterweed
Nuphar sp. – Yellow Water Lilly
Typha latifolia – Cattail

1981
Department of Environmental Quality Engineering

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(*Sagittaria latifolia*); and cattails (*Typha latifolia*).

The physical characteristics of the sediments, the water depth, and water chemistry influence the distribution of plants in the Lake. The forebays receive a heavy load of organics and silt from the Aberjona River causing turbid conditions in the Lake. This impedes light penetration which explains why floating water lillies dominate the forebays in mid-summer. Less turbidity in the main basin allows submerged plants such as pondweed to flourish.

The two forebays suffer from excessive aquatic vegetation, particularly the upper forebay. The mouths of the Aberjona, West Shore Inlet and Boat Club Inlet are also areas impacted by excessive vegetation. All these areas of extreme growth reflect not only the high ambient concentrations of phosphorus in the Lake, but also the points of input at the Lake inlets. The rooted vegetation in the main basin is not as severe as the forebays due to its depth, however, the entire shoreline of the main basin, including an area extending twenty feet from the outlet dam, harbor excessive rooted growth.

The rooted plants do have some value in that they provide a habitat and food source for some fish such as Blue Gills and Carp. The plants also help to filter out nutrients, metals and solids from the water. The decomposition of such biomass, though, can have a detrimental effect on fish by consuming large quantities of dissolved oxygen in the decomposition process.

Historic Comparison. The relative abundance of aquatic plants observed in 1981 as compared to survey results of 1974 show that there are currently many more areas impacted by excessive growth, especially in the forebays. In 1974, no growth was observed in the center of the forebays yet currently pondweed can be observed in large numbers in the center of each.

Phytoplankton

Existing Populations. Table 6-40 summarizes the classes of phytoplankton observed in the Lake.

Specific species found in Upper Mystic Lake during this study included:

Greens	Bluegreens	Diatoms	Flagellates
Sphaerocystis	*Anabaena*	*Cyclotella*	*Eudorina*
Pediastrum	*Anacystis*	*Stephanodiscus*	*Cryptochrysis*
Coelastrum	*Aphanizomenon*	*Rhizosolenia*	*Mallomonas*
Ankistrodesmus		*Tabellaria*	*Synura*
Scenedesmus		*Fragellaria*	*Chrysococcus*
Staurastrum		*Asterionella*	
Ulothrix		*Synedra*	
		Navicula	
		Melosira	
		Cocconeis	

TABLE 6-40: UPPER MYSTIC LAKE: SUMMARY OF PHYTOPLANKTON 1979-81
(Standard Areal Units)

DATE	GREENS	BLUEGREENS	DIATOMS	FLAGELLATES
4-30-79	580	0	1520	1180
7-16-79	2100	0	440	580
8-14-79	880	1200	140	600
8-14-79	980	3520	580	1160
8-14-79	1230	2360	360	880
9-11-79	5220	1400	2360	4040
10-18-79	0	2920	2840	440
11-15-79	0	2500	1020	40
12- 6-79	0	700	1040	480
3-24-80	300	0	6300	600
4-16-80	0	0	10,360	500
5-28-80	260	0	7060	0
6-24-80	2960	0	2720	0
7-24-80	21,680	120	1200	18,200
8-18-80	1620	5320	160	180
9-15-80	1040	9040	80	1700
10- 7-80	2200	2400	13,980	3600
10-14-80	580	2680	3000	540
11-12-80	380	3620	9260	160
11-14-80	100	2400	13,980	3600
12- 8-80	140	120	9220	1300
2- 4-81	80	0	3320	360
4-28-81	4860	0	5380	440
5-27-81	120	0	2820	100
6-25-81	1379	253	84	56
7-13-81	380	5140	1420	220
8-20-81	840	7200	0	280

Source: Mass. MDC, 1981.

Historic Comparison. Only a general comparison between the types of species now present and past populations is possible due to sampling differences between years.

In 1974, only two species of Bluegreens were found, Anabaena and Anacystis, during the summer and fall seasons. No Aphanizomenon was found. Aphanizomenon is sensitive to ammonia toxicity, particularly at levels found in the Lake at that time. In 1980-81, three species of bluegreens were found. These included Anabaena, Anacystis, and Aphanizomenon. The presence of Aphanizomenon reflects the decreased ammonia concentrations currently observed. Several species of green algae have remained through the years. These include Staurastrum, Pediastrum, Scenedesmus and Ulothrix. The diatom and flagellate populations have not changed significantly over the years.

Benthic Macroinvertebrates

Existing Populations. No benthic macroinvertebrates were observed in the Lake. Samples were taken in the forebays and main basin. Sediment and bottom water conditions in the Lake apparently prohibit any macroinvertebrates from living there. The fact that no benthic macroinvertebrates live in the lake indicates an extremely stressed environment.

Historic Comparison. The results of the survey in 1974 parallel the current situation.

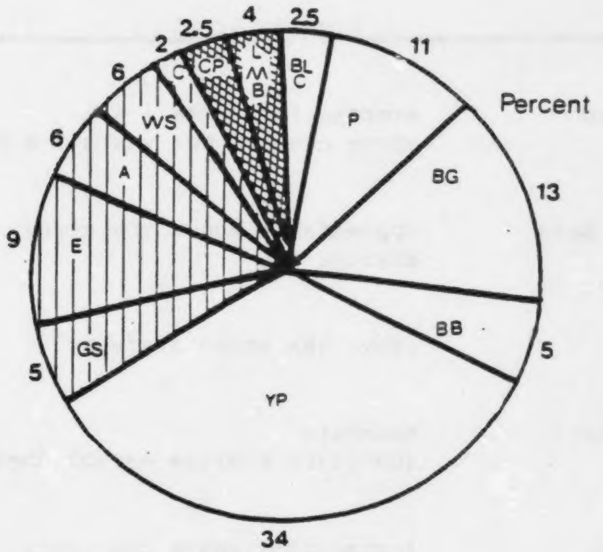
Fish

Existing Populations. Based on the results of the gill net and electroshocking methods, the following fish were found in the Lake:

Alewives
Black Crappies
Bluegills
Brown Bullheads
Carp
Chain Pickerel
Eels
Golden Shiners
Goldfish
Large Mouth Bass
Yellow Perch
White Suckers

Figure 6-10 shows the results of the timed shocking method. According to the Massachusetts Division of Fish and Wildlife, this method is the most accurate in reflecting the actual population in the Lake (Bergin, 1981). As can be seen, most of the fish in the Lake are classified as Pan (food) fish, the smallest percentage being Game fish. Since Game fish tend to be sensitive to polluted waters, the abundance of Pan and Forage fish in the Lake indicates stressful conditions. However, the growth rate data listed on Table 6-41, show that those fish which do live in the Lake are relatively healthy and recycle nutrients at a rate above the norm (Bergin, 1981). Local fishermen have, however, reported fish kills and an increase in flesh lesions and disease in 1982. These reports need to be further investigated.

Figure 6-10: UPPER MYSTIC LAKE FISH POPULATION DISTRIBUTION*



KEY

Fish Type

☐ Pan Fish ▥ Forage Fish ▩ Game Fish

Fish Species

LMB - Large Mouth Bass
P - Pumpkin Fish
BG - Bluegills
BB - Brown Bullheads
YP - Yellow Perch
BLC - Black Crappies

GS - Golden Shiners
E - Eels
A - Alewives
WS - White Suckers
C - Carp
CP - Chain Pickerel

* Population Distribution based on time-shock method

Data collected by Massachusetts Division of Fish and Wildlife, Acton, 1981.

Table 6-41: AGE AND GROWTH DATA FOR FISH FOUND IN THE UPPER MYSTIC LAKE (1981)

Species	Average Growth	Condition Factor
Yellow Perch	Average for years 1-4 Above average for years 5 & 6*	Ratings inaccurate
Largemouth Bass	Appreciably above the state average	Average
Bluegill	Above the state average	Average
Golden Shiners	Moderate (no state average established)	Above average
Pumpkinseed	Appreciably above the state average	Average
Chain Pickerel	Very grood growth, well above average*	Above average
Black Crappie	Average growth*	Average

* Inaccurate scale analysis possible; growth may actually be slower.

Source: Upper Mystic Lake Fish Survey conducted by Massachusetts Division of Fish and Wildlife, 1981.

Results of metal testing in fish flesh and a discussion of suitability for human consumption are discussed in the metals section (6.6).

Historic Comparison. No historic fish survey data could be found.

6.11 SUMMARY OF WATER QUALITY CONDITIONS

Water quality conditions in the Aberjona River and Upper Mystic Lake generally fall short of Class B standards for fishable/swimmable waters and the quality desired by local residents. The sources of pollution are varied but certainly urban runoff is a major contributor. The relative contributions of the various inputs to the Lake are summarized in Table 6-42.

Upper Mystic Lake is undergoing accelerated eutrophication as a result of the high nutrient loads entering the Lake. Application of the Vollenweider trophic status model clearly indicates that the Lake is eutrophic and its phosphorus loadings excessive. The Lake exhibits the classic symptoms of an eutrophic lake including high nutrient concentrations, abundance of aquatic vegetation, low transparency, depleted dissolved oxygen in deep waters, and inability to support cold water fish.

Phosphorus was determined to be the limiting nutrient in the Lake based on a N:P ratio of 50:1. All in-lake total P concentrations recorded exceeded the EPA guideline for controlling excessive aquatic vegetation. Phosphorus was particularly high in the forebays due to the high levels coming in from the Aberjona. Excessive plant growth is also most evident in the forebays due in part to these concentrations, and for rooted aquatics, to the shallow depth. The forebays are actually functioning as settling basins removing particulate phosphorus and other suspended material before it enters the main basin. As shown on Table 6-42 close to 80% of the P load to the Lake is from the Aberjona with baseflow urban runoff and the Sweetwater Brook sanitary connections contributing close to equal amounts. Additionally, phosphorus levels in the hypolimnion increased during the stratification period due to anoxic sediment release. The contribution of sediment release to the total P load was estimated to be close to 12%. High P levels were also found in the sediment samples collected. It was evident in the comparison of 1981 to 1974 data that phosphorus levels have increased and more sediment release is occurring.

Depleted oxygen levels are also a problem in Upper Mystic Lake. The main basin of the Lake begins thermal stratification in early May and remains stratified until fall turnover in late November or early December. Consequently the dissolved oxygen supply in the hypolimnion is finite during that period. That oxygen supply is quickly depleted by bacterial decomposition of organic matter and chemical oxidation and by July approximately 50% of the Lake volume (below 30 feet) was anoxic. A comparison of external loads of oxygen demanding material indicates that the oxygen required to oxidize the high nitrogen load could be as much as three times that required for the biochemical breakdown of organics (BOD). Additionally, the internal load of organics resulting from the abundant plant growth undoubtably also exerts a major oxygen demand although that demand was not quantified. The significance of these depleted oxygen levels is twofold: (1) oxygen requirements for cold water fish are not met in the deeper cooler waters where temperature requirements are met; and (2) under anoxic conditions phosphorus and metals are released from the sediment.

Table 6-42: SUMMARY OF UPPER MYSTIC LAKE POLLUTANT SOURCES - PERCENTAGE OF CALCULATED LOAD

	Aberjona River			Direct Drainage to the Lake							
				West Shore Inlet		Boat Club Inlet		Direct Drainage			
	Baseflow	Urban Runoff	Sweetwater Sanitary	Baseflow	Urban Runoff	Baseflow	Urban Runoff	Baseflow	Urban Runoff	Groundwater	Sediments
TSS	17.1%	37.7%	28.0%	0.3%	7.1%	0.1%	4.3%	0.2%	5.2%	*	*
BOD	29.9	59.3	6.7	0.5	1.0	0.4	1.1	0.4	0.7		
Total P	27.8	24.2	20.0	0.5	1.0	8.1	5.3	0.3	0.8	0.5%	11.6%
TKN	56.6	36.6	5.2	0.1	0.3	0.6	0.3	0.1	0.2	*	*
Nitrate	30.7	57.8	3.9	1.8	0.9	2.0	0.9	1.3	0.7	*	*
Ammonia	63.4	34.8	0.5	0.4	0.3	0.1	0.1	0.3	0.2	*	*
Aluminum	24.6	15.0	50.4	0.4	2.7	0.2	4.3	0.3	2.0	*	*
Arsenic	20.8	69.7	4.3	1.5	0.6	0.8	0.8	0.8	0.6	*	*
Copper	0	33.6	60.3	0.3	1.4	0.4	2.7	0.3	1.0	*	*
Iron	45.4	29.5	22.0	0.4	0.8	0.1	0.9	0.3	0.6	*	*
Lead	0	42.7	45.4	0	5.2	0.4	2.6	0	3.7	*	*
Manganese	19.6	76.0	3.4	0.1	0.1	0.1	0.2	0.1	0.1	*	*
Zinc	41.0	19.5	35.0	0.8	1.4	0.1	0.6	0.6	1.0	*	*

*Not calculated due to insufficient information.

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Several other major water quality problems were identified which are not necessarily associated with eutrophication including elevated levels of coliform bacteria, ammonia, and certain metals.

Elevated bacteria levels were recorded on several occasions in the forebays and at the Lake outlet. These present a threat to bathers in these areas and, elevated forebay levels could impact Sandy Beach under certain conditions. Several sources of sewage contamination have been identified. Combined manhole overflows to Sweetwater Brook are the major source of high coliform levels in the Aberjona. Two stormwater outfalls discharging directly to the Lake are also subject to sewer surcharging in the Winchester system. High coliform levels were also recorded in the Boat Club Inlet, the source of which needs to be identified as does that of the high outlet levels.

Ammonia levels in the Aberjona and Upper Mystic Lake are unusually high as a result of industrial waste disposal in the upper watershed. As mentioned above nitrification of this ammonia exerts a significant oxygen demand. Additionally, levels potentially toxic to aquatic life of unionized ammonia were recorded in the Lake in 16% of the surface samples collected. Levels in the Lake have decreased, however, from 1974 when 58% of the surface samples exceeded the toxicity criterion. High nitrogen levels were also found in the sediments.

Concern is also warranted regarding the concentrations of certain metals found in the Aberjona and Upper Mystic Lake. Copper, lead, cadmium, and zinc exceeded the 24 hour average or chronic criteria for the protection of aquatic life in the Lake. These violations were distributed fairly evenly throughout the Lake and only lead showed consistently higher violations during wet weather. Maximum criteria were violated for aluminum, copper, iron, and manganese. Of these, aluminum and iron showed higher violations in wet weather. All of the manganese violations were in the hypolimnion, a direct result of anoxic sediment release. High metal levels were also found in the sediments which based on the two rating systems applied can be considered heavily polluted.

Metal levels in fish flesh were also examined. Unfortunately, the only FDA standard which exists is for mercury. That standard was not exceeded. In their review of the data, the Mass. Division of Fisheries and Wildlife considered lead levels in bullheads high and recommended eating them in moderation. In an additional effort to determine the suitability of fish for human consumption, water quality data were compared to EPA criteria for protection of human health from ingestion of contaminated organisms - arsenic, lead and possibly cadmium exceeded these criteria. These criteria are rough guidelines indicating a potential problem.

As seen in Table 5-42 the relative sources of the metals vary with baseflow being a major source of iron, zinc, and to a lesser extent, aluminum; urban runoff is a major source of manganese, lead, iron, copper and arsenic; and the Sweetwater Brook sanitary connection a major source of aluminum, copper, lead, and zinc. Unfortunately, the sediment contribution could not be calculated based on the limited data collected but, based on accumulation seen after the stratification period. It may be a significant source of manganese, iron and zinc.

This chapter has discussed water quality conditions in Upper Mystic Lake and its tributaries and has identified the existing or potential impact of those conditions on Upper Mystic Lake. Chapter 7.0 will step back to a more generalized look at various urban runoff control options and in-lake treatment techniques. In Chapter 8.0 the identified problems will be reviewed and specific control options evaluated concluding with a guide for future work.

7.0 CONTROL OPTIONS

Controlling surface water pollution in the Upper Mystic Lake Watershed is a difficult task. Options include abating the pollution attributed to urban runoff and other known sources of pollution in the Watershed, as well as employing in-lake controls to alleviate problems resulting from contamination. Although these categories will be discussed separately in this chapter, it is important to remember that an effective watershed management plan needs to consider both these areas. In-lake control measures can temporarily alleviate the symptoms of contamination, such as algae blooms and weed growth, but most cannot solve the problem until the sources have been controlled.

This chapter presents existing control practices in the Watershed and then goes on to describe various runoff control options. There are three main categories into which urban runoff controls can be classified: (1) runoff volume and velocity reducers, (2) erosion and sedimentation controls, and (3) source controls. Within these categories, many options fall under the jurisdiction of local boards and commissions. These regulatory options will be discussed as a separate category so that the powers of these groups will be understood. A discussion of other urban runoff control options, both structural and nonstructural, and in-lake controls will then follow.

7.1 EXISTING CONTROLS

The cities and towns in the Upper Mystic Lake Watershed were surveyed to determine what urban runoff controls are presently being used. In most of the Watershed communities, standard controls such as street sweeping and catch basin cleaning, are the only measures in effect at this time. Only two municipalities acknowledge the use of other runoff pollutant control devices.

Every community in the Watershed sweeps its streets at least once per year, with many communities contracting out the work. This is usually done in the spring, taking a one to two week period to have all the streets cleaned (see Table 7-1). For catch basin cleaning, Woburn is the only community which cleans its basins biennially. All other communities remove the debris at least once per year (see Table 7-1).

The only communities which use other runoff control devices are Winchester and Woburn. Detention basins are contained within Winchester's stormwater collection system at Beacon Street, Horn Pond Brook Road, Waterfield Road, and Washington Street; and Woburn has sediment traps in their catch basins (Serratore, 1982; Simons, 1982). Both of these types of structures help to remove solids from stormwater.

More detailed information on the stormwater collection systems of the major communities in the Watershed can be found in Appendix E where the type age, and size of each system is described. Estimated budgets for the maintenance operations mentioned above are also included.

Table 7-1: FREQUENCY OF STREET SWEEPING AND CATCH BASIN CLEANING IN BASIN COMMUNITIES - 1982.

Cleaning Frequency	Arlington	Medford	Reading	Stoneham	Winchester	Woburn
Street Sweeping						
- General (all roads at once)	3 times/year	once/year	—	once/year	once/year	once/year
- Additional:						
Commercial	—	daily	twice/week	—	approx.	once/month
Residential	—	every 4-5 weeks	once/year	—	once/year	on-call
Main Roads				monthly		
Catch Basin Cleaning						
- General	once/year	weekly	twice/year	twice/year in central areas once/year in other areas	once/year	every 2 years

Sources:
- Arlington: R. Bowler, 1982.
- Medford: F. Loschi, 1982.
- Reading: W. Redford, 1982.
- Stoneham: J. MacKay, 1982.
- Winchester: D. Serratore, 1982.
- Woburn: R. Simons, 1982.

Table 7-2: LOCAL REGULATORY OPTIONS RELATED TO URBAN RUNOFF CONTROL AND THE PROCEDURES FOR ADOPTION.

Option	Statutory Authority	Who Adopts	Required Vote
Board of Health Regulations	M.G.L. Ch. 111 (M.G.L. Ch. 40)	City/Town Council Town Meeting	For Ch. 111, a majority vote of the Board of Health. For Ch. 40 see above.
Wetlands Bylaws	M.G.L. Ch. 40 (M.G.L. Ch. 131 & 40) (M.G.L. Ch. 40A)	City/Town Council Town Meeting	Majority vote of all members city/town council and majority vote of town meeting unless otherwise provided by ordinance, bylaw or chapter.
Local Bylaws	M.G.L. Ch. 40	City/Town Council Town Meeting	Majority vote of all members city/town council and majority vote of town meeting unless otherwise provided by ordinance, bylaw or chapter.
Zoning Ordinances or Bylaws	M.G.L. Ch. 40A	City Council Town Council & Town Meeting	2/3rds vote of all members city/town council and 2/3rds vote of town meeting.
Subdivision Rules and Regulations	M.G.L. Ch. 41 & 81m	Planning Board	Majority vote of entire membership.

Source: Mass. DEQE 1982C.

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7.2 REGULATORY CONTROL OPTIONS

Several laws in the Commonwealth of Massachusetts enable communities to adopt regulations and bylaws which may help to lessen the impacts of urban runoff on surface waters. The local groups primarily associated with these regulations are the board of health, conservation commission, and planning board. A summary of information on these regulatory options and procedures for adopting them is found on Table 7-2.

Boards of health are given the authority under Title 5 of the State Environmental Code to inspect and review plans for subsurface disposal facilities designed to handle sanitary waste flows of less than 15,000 gallons per day, and to regulate the disposal of septage. More stringent regulations than those stipulated in Title 5 can be adopted by the board to ensure greater protection against sewage contamination. Other areas under board of health jurisdiction include the protection of water supplies and the enforcement of State pesticide regulations.

The Wetlands Protection Act and local bylaws are the primary means through which conservation commissions are able to control urban runoff pollution. Commissions can stipulate conditions for development activities in areas protected under the Wetlands Act to ensure that precautions are taken to minimize negative impacts. Also, conservation commissions can enforce any local non-zoning bylaws which apply to these areas.

Planning boards can adopt zoning bylaws and subdivision regulations which may include conditions designed to preserve water quality and minimize the effects of urban runoff. Some common examples of zoning bylaws used for these purposes are described below.

Cluster Development Regulations - Regulate development allowing for the grouping of units in order to maximize the size of open space areas, while maintaining the development densities outlined in the general zoning regulations.

Earth Removal Regulations - Outline conditions for earth removal activities including provisions for temporary and permanent drainage and restoration standards. Can prohibit removal in areas where ground and surface waters may be affected.

Flood Plain Zoning - Regulates the type of development allowed on flood plains. Designed to protect life, property, and water supplies.

Performance Standards - Standards designed to regulate the impacts of specific land use activities. For example, standards can require developers to estimate any additional runoff generated from their activities, and require them to plan measures to control it.

Watershed Protection Districts - Areas designated as being sensitive which are especially regulated to protect ground and

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surface water quality. These districts are overlays on the existing zoning map. More stringent regulation of land use activities within these districts is possible.

Subdivision regulations are also used to control growth and development, but their requirements tend to be more specific. For example, these regulations can require a plan showing existing and proposed contours and grades, vegetative covers, storm drainage, methods of sewage disposal, and erosion and sedimentation controls. The use of certain materials or designs, such as requiring porous pavement driveways, may also be included in these regulations.

In combination, the three authorities can have a significant impact on the control of urban runoff in developing areas. However, it is important that these groups coordinate their activities. Through careful planning and regulation a community can grow while it preserves the quality of its natural resources.

7.3 STRUCTURAL AND NONSTRUCTURAL CONTROL OPTIONS

Although it is possible to categorize urban runoff controls in several ways, here they are discussed in regard to the problems they address: runoff volume and velocity reduction, erosion and sedimentation control, and pollutant source control. These measures can be structural or nonstructural controls, and are designed to either reduce runoff and/or runoff contamination, or to treat polluted runoff.

There are numerous options available, however, only the more commonly used controls are presented here. Their effectiveness has been documented, and in most instances estimated costs are available. Each option will be described, followed by information pertinent to their practicality. Pollutant removal and reduction rates, will be discussed at the end of this section.

Runoff Volume and Velocity Reduction

The control options discussed in this section are primarily designed to reduce runoff volume and velocity. Both of these hydraulic characteristics of stormwater influence the impact on receiving waters through both quality and quantity considerations. Higher volumes of runoff can cause flooding and can increase the velocity of flow. This in turn increases the erosive forces of runoff, causing larger quantities of pollutants to wash off the land into surface waters. Three common measures designed to control these problems are discussed below.

Detention/Rentention Basins. These are impoundments designed to reduce the amount or rate of runoff from urban areas either by releasing the stormwater at a controlled rate, or by allowing the water to evaporate and infiltrate into the underlying soils.

The basins can be wet ponds which are designed to hold a normal level of water with additional capacity for stormwater; or they can be dry basins which are designed to empty periodically. In some cases retention areas can be incorporated into streams, helping to reduce the effects of runoff. Multipurpose basins can be designed, with secondary recreational, aesthetic, and sediment removal value. Ice skating is a common recreational use of wet ponds. Ponds designed for water infiltration have an added benefit of groundwater recharge; however, care must be taken to ensure that the contaminants in the runoff will not pollute the aquifer.

To ensure the efficiency of the basin, certain maintenance practices are necessary. Periodic removal of sediments and aquatic weeds is needed if the detention capacity of the basin is to be maintained. Also, landscaping of the area surrounding a wet pond may be required. Maintenance of the spillway is needed to ensure that the basin will not flood downstream areas. Also, safety features, such as fencing, may be required in some residential areas to prohibit access.

A problem sometimes associated with wet basins is their capacity to support mosquito larvae. For basins adjacent to residential areas, this may especially be a nuisance. Stocking the pond with larvae-eating fish or vary-

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ing the water level in the basin can control this problem.

The design and construction of detention/retention basins takes into consideration the size of the drainage area and other basin characteristics, thus making their costs vary. Costs of detention basins investigated by other NURP projects ranged from under $400 to over $5 million for capital costs alone. Annual operating costs averaged $2,742 (Midwest Research Institute, 1982).

Grassed Waterways and Filter Strips. The capacity of grass to slow runoff flow, filter out pollutants, and allow for infiltration can be used as a control method. Grassed waterways (swales and channels) are used to slow the velocity of concentrated flows of runoff. They are practical along roads in place of curbs and gutters in low to moderate density residential areas. Filter strips act as buffer zones through which runoff travels. Their primary purpose is to filter out contaminants; thus they are commonly used along the perimeter of disturbed or impervious areas.

The costs for grassed waterways and filter strips vary according to size, design, and means of construction. Costs for site preparation and sodding range from $2,400 - $3,600 for the initial planting and $50 - $100 per acre for first-year maintenance (1979 dollars) (Virginia State Water Control Board, 1979).

Porous Pavement. Roads can be constructed using permeable materials which allow runoff to infiltrate. This design reduces the volume of runoff generated and the peak flow rate, while increasing the lag time between precipitation and the resulting runoff. There are several types of porous pavement in existence today. Open graded asphalt concrete is the most popular due to its physical stability, low cost, and conventional means of application which is paving (Field, et.al., 1982). Currently, the use of porous pavement is largely limited to parking lots due to the lack of information on its long-term durability. Research shows much hope for its use in low traffic areas.

There are many advantages associated with the use of porous pavement. In addition to those mentioned above, porous pavement may:

- improve the quality of surface waters previously contaminated with runoff;
- reduce or eliminate the need for curbing and stormwater collection systems;
- preserve the natural drainage of the area;
- increase groundwater recharge;
- improve road safety through higher friction coefficients, reduced hydroplaning, and better visibility; and,
- reduce or eliminate puddling - a nuisance to pedestrians and motorists (Field, et.al., 1982).

Unfortunately, there are some substantial disadvantages to porous pavement use which cannot be ignored. In order for the pavement to remain effective, a special maintenance program is necessary. The pores in the pavement are subject to clogging with sediment and debris, thus vacuuming or flushing is required. Both of these maintenance activities have been found to be adequate.

Proper design is important if the system is to remain functioning. The type of subsurface soil is crucial as it must be able to sustain the weight of traffic yet remain permeable. Individual site design which considers the local geology, hydrology, and climate is required. Also, proper design should eliminate any problems with frost heaving, a point documented by tests conducted in Rochester, New York (Field, et.al., 1982).

The quality of the runoff must also be examined to determine if its infiltration may threaten the quality of underlying aquifers. This situation can be remedied by designing the system to collect the runoff for transport to a detention area; or a seal can be placed above the aquifer.

Although these disadvantages are important, careful planning can eliminate most of them. Also, continued research in this area should lead to further improvements.

The cost of constructing a porous pavement roadway is competitive with prices for conventionally paved roads as long as an extensive stormwater collection system is not required. At this time, some form of backup system is included in most areas because of the novelty of porous pavement. The cost effectiveness of using porous pavement must be determined on a site by site basis due to the individual design considerations necessary. An example of costs given by the Virginia State Water Control Board (1979) lists porous pavement prices as ranging from about $8 to $10 per square yard, in comparison to conventional asphalt pavement costs of approximately $5 per square yard (1979 dollars).

Erosion and Sedimentation Controls

The controls presented in this section are erosion prevention measures and treatment devices which encourage sediment deposition. Sediments which enter surface waters through runoff can fill in channels and cause turbidity problems. Also, nutrients and metals adsorbed to solids can promote eutrophication or be toxic to aquatic organisms. The controls discussed below can help to prevent these problems. More details on erosion and sedimentation control can be found in Erosion and Sedimentation Guidelines (DEQE, 1982e).

Diversions. Diversions are structural controls which prevent runoff from travelling across a designated area thus minimizing erosion. Some common diversions include:

> Diversion Ditches - channels designed to intercept and laterally divert runoff from slopes, thereby regulating runoff velocity and erosion potential. May be temporary or permanent, with or without soil ridges.

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Diversion Dikes - ridges of soil (temporary) or other non-erodible material (permanent) designed to prevent overland flow across erodible areas. Commonly used along slopes and roads.

Slope Drains - conduits built into a slope, designed to transport drainage waters from above the slope to a safe discharge point at the base.

When used properly, diversions can help to prevent unnecessary erosion on both disturbed and stabilized areas. Costs of constructing these controls vary with design and site characteristics.

Slope Stabilization. Temporary or permanent controls can be used on slopes to inhibit erosion. Commonly, a temporary stabilizer is used until a more permanent vegetative cover can establish itself.

Mulches, such as hay, wood chips, and netting, are common temporary covers which allow moisture to penetrate the soil while reducing runoff velocities and the effects of rainfall impact. Grasses and legumes, common permanant covers, are then able to begin their growth beneath these mulches.

In some areas, slopes are too steep to maintain a permanent vegetative cover. At these sites, non-vegetative controls, such as retaining walls, may be required.

Costs of both permanent and temporary slope stabilization controls vary too greatly to estimate costs. The type of control employed and characteristics of the site must be considered to properly assess costs.

In-Line Mechanisms. Swirl and helical bend concentrator/regulators and teacup solids separators have been developed as stormwater treatment devices. The swirl concentrator/regulator is a circular device connected at the point of discharge from a stormwater collection system. Flow is regulated using a central circular weir spillway, while solids are removed through swirl action. The solids concentrate is transported to a treatment plant while the stormwater effluent is commonly discharged to a detention basin or into surface waters.

A helical bend concentrator/regulator is also attached to a stormwater outfall; however, treatment occurs through the secondary helical motion of fluids. The overflow is forced over a side weir where it is discharged. Solids are concentrated at the end of the chamber where they are discharged to the sewer line. A study of these two mechanisms showed that their effectiveness varied with characteristics of the storm event (Environmental Design and Planning, 1982).

Teacup solids classifiers are improved versions of the swirl concentrators, as they are more efficient at removing finer solids particles. Free and forced vortex fields are used to remove settleable and floatable solids and liquids.

The costs of these devices depend on the size needed to handle the stormwater generated from the given drainage area. In older systems where runoff is discharged at several points within a community, these controls may not be practical as each pipe would need a device. Where stormwater can be intercepted to discharge at central points, the use of one of these devices may be practical. Usually the costs are a few hundred thousand dollars.

Sedimentation Basins. Temporary or permanent basins can be designed primarily for the purpose of sediment retention. They are similar to detention/retention basins as they can be wet or dry ponds, in-stream or separate, and may develop similar problems such as excessive weed growth and mosquito breeding. The basic difference is that sediment basins are designed to maximize sediment deposition while detention basins are mainly concerned with peak flow reduction.

Sedimentation efficiency can be increased by reducing the flow velocity and by modifying the basin outlet. Baffles made of sheeting material or vegetation can be used to meander the current within a basin or in streams. This slows the flow thereby encouraging solids deposition. Placing the outlet pipe in the center of a rounded basin can increase sedimentation by using centrifugal force. As the outflow forms a vortex around the pipe, sediments are forced to the sides of the basin where deposition occurs.

Periodic sediment removal is required, as well as routine spillway and landscape maintenance. The annual operation and maintenance costs and the initial capital expenses are site specific, but should be comparable to prices given for detention basins.

Sediment Traps. The sediment runoff has picked up from erosion prone areas can be controlled by constructing sediment traps. These traps, which are usually temporary, include:

> Filter Berms - ridges of gravel or crushed stone designed to filter sediments from runoff. Commonly used across a graded right-of-way or in drainage ditches.
>
> Sandbag or Straw Bale Barriers - Semi-permeable walls constructed of sandbags or straw bales which serve to filter out sediments. Typically, barriers are used at storm drain inlets, along drainage ditches, and across rights-of-way.
>
> Filter Inlets - gravel or crushed rock placed at edges of storm sewer inlet structures to filter out sediment before runoff enters the stormwater collection system.

Maintenance of sediment traps is important if they are to function properly. Removal of sediment after each storm may be required in some areas. Sandbag and straw bale barriers should be checked periodically to ensure that they are firmly anchored and that they do not need to be replaced.

The costs of filter berm and inlet construction are approximately $5 - $6 per foot (1972 dollars). Sandbag and straw bale barriers cost $2 - $3 per foot and $3 - $4 per foot, respectively (1972 dollars) (Mass. DEQE, 1982).

Catch Basin Cleaning. Proper maintenance of catch basins contributes to improved water quality. Catch basins collect debris contained in the runoff entering storm drains. Catch basin cleaning can be done manually or by using an eductor or vacuum. The latter two methods are more labor-efficient than cleaning by hand, but usually some manual removal of debris is required to ensure adequate cleaning (U.S. EPA, 1977).

The required frequency for catch basin cleaning is dependent on local conditions such as the sump capacity, accumulation rate of solids, climate, and adjacent land use. The minimum rate of cleaning should ensure that catch basin capacity is not exceeded to a point where its outlet is blocked. To maximize solids removal, the sump must be kept clean providing storage for the solids. Catch basin clogging is an obvious indication of insufficient maintenance. The median rate for cleaning, calculated from a 1973 survey of cities in North America, was once per year (U.S. EPA, 1977).

The costs vary with the method of cleaning. Manual removal of debris is expensive and time-consuming. The Castro Valley NURP study had an average cost of $6 per basin, but local influences may vary this amount (Midwest Research Institute, 1982).

Wetland Plants. Bulrushes, cattails, and other wetland plants are naturally able to biologically and physically treat stormwater effectively, working in symbiosis with microorganisms. The major contaminants removed are nutrients, primarily nitrates and phosphates. Other treatment capabilities include rapid neutralization of extreme pH conditions, reduction of COD levels, increases in dissolved oxygen content, and the break-down of phenols and cyanide groups (Virginia State Water Control Board, 1979).

Wetland vegetation can be planted within existing ponds, or established wetlands can be upgraded to improve their treatment efficiencies by increasing retention time. Often, these areas can support wildlife, an added aesthetic benefit.

The costs of establishing wetland treatment areas depend on the prices for plant material, site preparation, planting, and maintenance.

Pollutant Source Controls

Runoff pollutant source controls are preventative practices designed to eliminate or reduce the level of pollutants picked up and transported by stormwater. In general these controls are "housekeeping" measures practiced by the community department of public works, and by the citizens. The two categories below, operation and maintenance practices and public education programs, outline some activities these two groups can practice to attain source control.

Operation and Maintenance Practices. Practices, such as street sweeping and road maintenance, can help to control runoff pollutants at their source. The main objective of street sweeping is to control materials which are a nuisance from the standpoint of aesthetics and public safety. As such, it does not necessarily address pollution control. Mechanical sweeper, sometimes vacuum-assisted, are the most common types of equipment used. In some areas manual sweeping is also used. The machines travel at slow speeds along the gutter while rapidly rotating brushes push solids onto a conveyor for collection.

The effectiveness of street sweeping in removing pollutants is dependent on several factors including the sweeper efficiency, the frequency and timing of sweeping, the speed of the equipment, the number of passes, the type of equipment used, and the pavement conditions. Compliance with parking regulations is also important since most of the material to be removed is close to the curb. Street sweeping is more effective in removing suspended solids, including lead, than in lowering the chemical or biological oxygen demand or removing other contaminants such as phosphorus. It reduces the particulate loadings and some dissolved loadings by reducing the amount of polluting materials available along roadways. However, for the parameters that it does remove, street sweeping is generally cost effective, representing a much lower cost ($/lb removed) for certain substances than would be required to treat the runoff in order to remove these contaminants. The capital cost of street sweeping is low in comparison with other management alternatives, particullarly since most towns already own the machinery. The effectiveness of solids removal increases as roads are cleaned more frequently, up to a rate of two to three runs per week. Beyond this level more cleaning will have little additional benefit (U.S. EPA, 1982). The costs of street sweeping vary from $5.95 to $23.36 per curb-mile (U.S. EPA, 1982).

Public Education Programs. Local governments or special interest groups can initiate programs to increase the public's awareness of their role in preventing stormwater contamination. Many of the pollutants picked up by urban runoff have been deposited on the land surface as a result of human activity. Cars give off heavy metals in their exhaust and may leak oil and grease. The use of fertilizers on lawns and gardens may leave nutrients susceptible to wash-off. Also, the accumulation of litter along roads can lead to high biochemical oxygen demand in runoff.

In order to reduce the availability of these contaminants, campaigns can be undertaken to inform the public about the effects these pollutants may be having on local surface waters which receive stormwater, and what individuals can do to minimize the contributions from these sources. One means of getting this information to the public is through brochures. Pamphlets which discuss proper maintenance of automobiles, best management practices for fertilizer use, littering and solid waste removal requirements can present clear and concise information on these issues. The content of these pamphlets should include any other incentives which may encourage individuals to implement the suggestions made. Unfortunately, not all people are environmentally conscious, thus added incentives such as reductions in fertilizer costs through more efficient application practices, should help to encourage a positive response. Strictly enforcing any local ordinances against littering may also help to reduce contamination from this source. Usually, a fine for littering is charged.

In order for public education programs to be an effective means of runoff pollutant control, many people need to respond to the suggestion made. Although an individual can decrease the level of pollution he generates, large

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numbers of people need to respond if a marked effect is to be seen in runoff quality. For this reason the effectiveness of this type of control will vary greatly from community to community, depending on the desire of the citizens to alter their habits for water qualtiy protection.

Control Efficiencies

The effectiveness of an urban runoff control is important to consider when developing a stormwater management plan. The removal or reduction rate should be maximized while costs are minimized. Often the higher priced control measures are more efficient; therefore a community should carefully consider what level of runoff control it desires, and what price it is willing to pay for it before controls are selected.

Determining the efficiencies of controls often leads to the same problem encountered with pricing: many times they are too varied or site specific to estimate. Such is the case with public education programs, as their effectiveness is largely dependent upon the attitude of the citizens. For other controls, studies have been conducted and ranges of efficiencies have been estimated. The maximum percentages of removal or reduction obtained from such studies for most of the controls discussed in this section are given on Table 7-3.

As shown, the controls which treat contaminated runoff, such as swirl concentrators, tea cup solids classifiers, sedimentation basins, and wetlands, tend to be more efficient than the preventative measures. However, two of the preventative controls, grassed waterways and porous pavement, appear to be comparably efficient, achieving up to 90% erosion reduction and 85% runoff infiltration respectively.

Most practices use the control of solids as their means of preventing or treating contamination, often causing the removal rates for other parameters, such as nutrients and metals to be dependent upon their association with the solid fraction. The amount of pollutants found adsorbed to sediments is a site-specific trait, varying with such factors as the local soil type and water quality. Dissolved pollutants are difficult and costly to control, thus preventative practices are important. Controls which affect their source, such as fertilizer use and automobile maintenance campaigns, as well as measures which improve on-site infiltration are best suited for controlling the dissolved fraction.

The efficiencies shown here are just one category to consider when selecting urban runoff controls. Cost and applicability to the area and problem are also important. Later in this report these considerations will be analyzed for the Upper Mystic Lake Watershed, and specific recommendations will be made.

Table 7-3 : MAXIMUM PERCENTAGE OF REMOVAL OR REDUCTION

Control	BOD	Nutrients	TKN	TP	TS	SS	Settleable Solids	Copper	Lead	Zinc	Erosion Rate	Peak Runoff Rate	Reference
Detention Basins	25	25				25							U.S. EPA, 1977a
Grassed Waterways											90		Virginia State Water Control Bd., 1979
Porous Pavement												85	R. Field, et al., 1982
Erosion Controls	25	25				50							U.S. EPA, 1977a
Swirl Concentrator	60					60	90						U.S. EPA, 1978
Teacup Solids Classifier	40					90	100						Eutek Systems, 1978
Sedimentation Basins													
without chemicals	30		38	20		60	95						U.S. EPA, 1978
with flocculation	80					90							MAPC, 1977
Wetlands Treatment				78		94							U.S. EPA, 1977b
Catch Basin Cleaning	43				56								Virginia State Water Control Board, 1979
Street Sweeping				10	20			10	35	10			U.S. EPA, 1982 draft

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7.4 IN-LAKE CONTROLS

The problems commonly found in polluted lakes can be alleviated through source controls such as those listed previously; however, in-lake measures can also be used to obtain faster results, or to temporarily relieve symptoms where contamination still exists. The following section will address methods of controlling algae blooms, excessive weed growth, oxygen deficiencies, and contaminated sediments.

Aeration

Hypolimnetic Aeration. There are two methods of aerating a lake which will help to improve water quality. One technique entails aerating the hypolimnetic waters alone, without disrupting thermal stratification. The primary purpose of hypolimnetic aeration is to add oxygen to anaerobic bottom waters. An additional benefit is the removal of some unwanted compounds from the water column.

This form of aeration is accomplished by forcing hypolimnetic waters to the surface via a tube lowered into the lake. Care must be taken to ensure that bottom sediments are not stirred up in the process. The waters are held separate from the epilimnion while being exposed to the air. At this time the water is oxygenated and gases, such as hydrogen sulfide and ammonia, are lost to the atmosphere. Some of the ammonia may be converted to nitrate which is returned to the hypolimnion when the water is piped back down. However, if nitrogen concentrations in the lake are high, nitrite might build up in the bottom waters and create toxic conditions for fish.

Once the hypolimnion is oxygenated, some compounds are precipitated from the solution. Iron changes from the ferrous form, found as a free ion in anaerobic waters, to the ferric form which is commonly precipitated out as ferric hydroxide ($Fe(OH)_3$) and ferric phosphate ($FePO_4$).

These changes in the water can have secondary beneficial impacts. The oxygenated hypolimnion may be able to support a cold water fishery. However, if the sources of organic matter are not controlled, periodic or continual aeration will be necessary to maintain the oxygen level required to support fish. Also, phosphorus concentration reductions, due to precipitation with iron, may have an inhibiting effect on algae growth; and the taste and odor problems associated with hydrogen sulfide can be alleviated.

Artificial Destratification. The second form of aeration is artificial destratification or circulation which can be achieved by injecting air which is under pressure through a perforated pipe placed in the deepest portion of the lake. The force of the air overcomes the density difference between the epilimnion and hypolimnion causing the entire water column to circulate. Again, efforts should be made to avoid disturbing the sediments.

Artificial destratification should be started early in the spring before full stratification has occurred. If stratification develops, the hypolimnion may become nutrient rich due to nitrogen and phosphorus release during the decomposition of organic matter. If the water column is stratified, the nutrients will remain trapped in these bottom waters. Once circulation is initiated, the mixing will bring these nutrients into the epilimnion where an algae bloom may develop.

As with hypolimnetic aeration, artificial destratification will remove gases and iron compounds which may contain phosphorus. The main difference is that the temperature will be uniform, which in most cases eliminates the capability of establishing a cold water fishery.

Artificial circulation must be done periodically to keep the water column from stratifying and developing anoxic bottom waters. The required frequency of aeration will vary with lake characteristics.

The costs of developing an artificial destratification system are approximately $100,000, with monthly operating costs ranging from $200-$500. The costs of hypolimnetic aeration are higher than artificial circulation since twice the pipe length is needed and the system design is more complex (Di Pietro, 1982).

Biological Treatment

This form of in-lake control introduces a foreign species to the lake which will attack a nuisance organism. Some examples include herbaceous fish and fungi which will eat aquatic weeds and algae. This method may be desirable as it uses a natural control predation to manage the unwanted organism. However, there is always the concern that the predators themselves may become a nuisance since there may not be a natural predator present to control their population. This problem arose in Florida where the Mozambique mouthbrooder was introduced to control algae and some rooted aquatic plants (U.S. EPA, 1980b). Conversely, the new environment may not be able to support the new species, thereby making its use as a control ineffective.

Studies of a fungus (*Eichornia crassipes*) which attacks water hyacinth, and white carp (*Ctenopharyngodon idella* Val.), which eats almost all types of vegetation, show promising results. Yet, at this time species are not allowed to be introduced to aquatic systems except for study purposes (U.S. EPA, 1980b).

Another detriment of using biological control is that the foreign species helps to accelerate nutrient cycling. If the target organisms are aquatic weeds, the nutrients released by the predator may then promote algae growth.

The effectiveness of the predacious species should last as long as the population remains viable. The costs of establishing the population would vary for the different species.

Chemical Treatment for Vegetation Control

There are many types of herbicides and algicides which can be used to control nuisance vegetation in lakes. When applied, these chemicals kill

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the plants or algae within the lake where they then settle and decompose on the lake bottom. During decomposition oxygen will be consumed and nutrients released. This could result in anoxic conditions in the hypolimnion, and additional weed and algae growth. Supplemental applications of chemicals in one growing season may be needed to control excessive growth.

Additional problems to consider are the long-term effects of the chemical residues in the aquatic system. Many of these chemicals are not readily degraded and their residues may prove to be toxic to aquatic organisms after prolonged exposure. Copper sulfate and sodium arsenate, two commonly used chemicals, have been known to accumulate in sediments to toxic levels. The high cost of the chemicals and the necessity of repeated applications is also a disadvantage. Because there are so many drawbacks associated with this form of temporary and localized vegetation control, other methods are often more desirable.

Dredging

Dredging, the mechanical removal of sediments, can be done under wet or dry conditions. Hydraulic dredging is the most common wet method, where a slurry containing sediments is picked up by suction. These dredges generally have some form of rotating head which suspends the sediments in front of a vacuum-like device. Dry dredging is done in conjunction with drawdown. Sediments are left to dewater. They are then removed using conventional excavation machinery.

One benefit from dredging is the removal of nutrients. In many lakes the contribution of nutrients from the sediments can be substantial; thus, removal of the upper nutrient-rich layers may lower the eutrophic condition of the lake. In addition, there may be temporary removal of rooted aquatic plants and some basin-deepening which can limit the light penetrating to the plants.

There are some disadvantages which may be encountered when dredging is used. Under wet conditions dredging may resuspend the finer particles, causing a turbidity problem and the release of nutrients and toxic substances. Also, the disposal of the sediments may be difficult. If they are classified as hazardous waste, special handling is required.

The duration of the benefits achieved from dredging depends on the sediment load from incoming sources. If nutrient and sediment sources are controlled, dredging may effectively reduce the level of nutrients released from the sediments. Rooted aquatic plants will eventually reestablish themselves, but if their root systems have been destroyed through dredging, it may take a year or more for the growth to return.

The costs of dredging range from $1 to $15.70 per cubic meter depending on the method used (1980 dollars). Hydraulic dredging is generally more expensive than excavation during lake drawdown. An average cost for the northeast was estimated to be $5.63 per cubic meter (1980 dollars)(U.S. EPA, 1980b).

Flushing

Flushing a lake is a major task where contaminated water is drained from the lake basin and replaced with high quality water. This procedure allows for the rapid removal of dissolved and suspended pollutants, but is not effective for any length of time unless inputs to the lake are controlled.

In order to properly implement lake flushing, a large source of high quality water must exist as well as the capability to remove the old water. In some instances, structures which control the water level may already exist. This will help to keep costs down, but the cost of refilling the lake may be too high if a water source is not readily accessible. These variables make it difficult to estimate costs.

Other concerns include the impacts on the lake's aquatic environment and downstream hydrology. Fish and zooplankton populations may be destroyed, and downstream areas may flood if the release of water is not carefully controlled. All these problems may make this control impractical in many areas.

Harvesting

The mechanical or manual removal of nuisance vegetation from a lake is known as harvesting. Usually, rooted weeds are the target organisms. Manual removal, where care is taken to extract the entire root system, is the most effective form of harvesting. Mechanical removal initially achieves the same vegetation-free state as manual harvesting, but regrowth is usually more rapid. After mechanical harvesting, some rooted aquatics may grow back within the same season, but usually this control is effective for a year. Regrowth can also be reduced by harvesting more than once per year, and by increasing the depth at which the weeds are cut (U.S. EPA, 1980b).

As with most in-lake treatments, there are both advantages and drawbacks to harvesting. To be optimally effective, the weeds which are harvested should be removed from the water and properly disposed. If weeds are left to decompose in the lake, the dissolved oxygen in the hypolimnion may be depleted and the nutrients tied up in the vegetation will be released, possibly causing an algae bloom. Approximately 6 pounds of phosphorus and 50 pounds of nitrogen can be removed per acre harvested (U.S. EPA, 1980b).

Collection and disposal of harvested weeds helps to prevent blooms, but they may still occur if nutrient inputs to the lake have not been controlled. The nutrients normally consumed by the weeds will then be available for algal uptake and more severe blooms may develop.

The removal of weeds may also lead to turbidity and sedimentation problems. Often weeds establish themselves at inlets and act as natural filters by helping to remove sediment from the inflowing water. When the weeds are removed, silt may remain suspended in the lake water as it travels into the basin, thereby creating turbidity problems. Also, the new site of silt deposition may not be favorable.

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There are many types of mechanical harvesters available for use. The most efficient type cuts the weeds with a sickle bar, collects them using a conveyor, and transports the weeds to shore for proper disposal. Another type, known as a hydrorake, pulls the weeds from the sediments. Although this machine is particularly effective on water lilies, care must be taken to avoid disturbing the sediments.

The costs of mechanical harvesting, including labor, equipment depreciation, and disposal expenses, range from $70 to $100 per acre (1980 dollars) (U.S. EPA, 1980b).

Over-Winter Drawdown

This in-lake control uses variations in the water level as a method of improving the lake environment. Several areas can be affected by lowering the water level in the lake, such as rooted aquatic plants, exposed sediments, and fish populations.

Reductions in weed growth from drawdown are only seen with certain rooted aquatic plant species. Table 7-4 shows which species will decrease, increase, or remain the same in number when subjected to over-winter drawdown. In order for vegetation to be reduced, sufficient drying and freezing of the roots is necessary. Sediments must be dewatered for at least 21 days prior to the time when frost sets in or else the roots will not be affected by the freezing. In addition, the period of freezing must last at least one month (Mass. DEQE, 1981d). If this form of treatment is employed over many successive years, freeze resistant plants may move in and make this form of treatment ineffective.

During dewatering, the sediments will be consolidated, making a firmer lake bottom. This is often desirable if the lake is used as a swimming area. Also, if adequate access exists, sediments can be readily excavated using conventional methods while the level is low (see Dredging).

Hydrologically, over-winter drawdown may not be feasible. Groundwater recharge may make sufficient dewatering of the sediments impossible. Conversely, shallow wells along the lake may go dry when the water level is dropped and the lake may not refill in the spring. The downstream hydrology can also be adversely affected.

Other disadvantages include restricted winter recreational use, potential increases in algal blooms if nutrient sources are not controlled, and the unpleasant aesthetics of the exposed site. Permanent structures such as docks may also be damaged.

The cost of drawdown can be minimal, especially if structures for managing the water level in the lake have already been constructed.

TABLE 7-4: AQUATIC VEGETATION AFFECTED BY OVER WINTER DRAWDOWN

Vegetation Decreasing in Abundance:

Chara vulgaris (Muskgrass)
Eichhornia crassipes (Water Hyacinth)
Nuphar spp. (Water Lily)

Vegetation Increasing in Abundance:

Alternanthera philoxeroides (Alligatorweed)
Najas flexilis (Naiad)
Potamogeton spp. (Pondweed)

No Change or Clear Response:

Cambomba caroliniana (Fanwort)
Elodea canadensis (Elodea)
Myriophyllum spp. (Milfoil)
Utricularia vulgaris (Bladderwort)

Source: U.S. EPA, 1980b.

Phosphorus Precipitation/Inactivation Using Chemicals

The chemical control of phosphorus in a lake system can be accomplished in two ways. Either the phosphorus dissolved in the water column can be precipitated to the sediments, and/or the phosphorus bound in the sediments can be chemically inactivated. The purpose of this form of lake treatment is to reduce the amount of phosphorus available for algae and plant uptake, thus controlling nuisance growth. The transparency of the water and dissolved oxygen concentration in the hypolimnion are also improved when the vegetation is reduced.

Several chemicals can be used to react with the phosphorus, but those most commonly employed are aluminum compounds such as aluminum sulfate (alum) and sodium aluminate. These chemicals work in three ways: aluminum phosphate may be formed, phosphorus containing particles in the water column can be entrapped, and phosphorus may be absorbed to the surface of aluminum hydroxide (U.S. EPA, 1980). Phosphorus precipitation is achieved by adding the chemicals to the epilimnion, where they drop through the water column precipitating out the phosphorus. This form of treatment will not control the phosphorus release from the sediments unless large doses are used.

Phosphorus inactivation is a longer-term control than precipitation. The chemicals are injected to the deep waters only, where they form a floc which covers and reacts with the sediments to bind the phosphorus. This treatment is not effective for rooted macrophytes as they can still take phosphorus from the sediments via their roots. This treatment may actually increase their growth if the improved water transparency allows for greater light penetration.

Both precipitation and inactivation can be achieved from one treatment. Enough of the chemical can be added to the epilimnion to ensure that an adequate floc layer develops on the sediments.

Chemical applications should be done carefully to minimize adverse effects. A lowering of the pH and increases in the concentrations of dissolved metals such as aluminum are common. By adding a neutralizing solution at the same time the chemical is applied and carefully determining the dose of chemical needed these problems can be alleviated (Mass. DEQE, 1981e). An additional problem may develop when the chemical used contains sulfate. If sufficient quantities build up in the hypolimnion and are subjected to anoxic conditions, hydrogen sulfide may be formed. Precipitation, which requires smaller doses than inactivation, will have fewer side effects, but the benefits do not last as long.

The length of time that either treatment remains effective varies; if nutrient inputs to the lake are not controlled, the duration will be short. Also, the mixing of the bottom waters due to influences such as wind action or motor boats, can stir up the floc and destroy its effectiveness. Chemical treatment has been reported to remain effective for at least 5 to 6 years in some lakes (U.S. EPA, 1980).

The costs of these treatments vary with the methods and chemicals used;

however, estimates range from $400-$500 per hectare (U.S. EPA, 1980b).

Sediment Covering

Various materials can be used to cover lake sediments for the purpose of preventing nutrient and metal exchange between the sediments and the water column, or to inhibit rooted aquatic plant growth. Some covers are capable of accomplishing both of these tasks. The two categories of covers used for these purposes, physical and chemical, usually achieve the desired results by creating a barrier between the sediments and the water. In some cases, plants are controlled by blocking the sunlight needed for their growth. Chemical covers have the added benefit of chemically absorbing substances such as phosphorus.

Two common chemical covers are fly ash and clay. These materials have cement-like properties which help to form a seal over the sediments. Although their nutrient-binding capabilities are favorable, there are also disadvantages associated with their use. Fly ash may generate high pHs and release toxic quantities of heavy metals such as boron, molybdenum, selenium, arsenic, and mercury. These problems outweigh the benefits; thus, the use of fly ash as a sediment cover is not recommended at this time (U.S. EPA, 1980b). Clays may be used effectively without severe side effects, but it may be hard to obtain good clay settleability.

Sheeting, netting, sand, and gravel are typical physical covers. All but netting act as barriers between the sediments and the water column, unless perforations are made in the sheeting. Fiberglass netting is designed for the purpose of weed inhibition only and achieves this through smothering plants and blocking of light. Nutrient and metal exchange are not inhibited.

Sheeting (made of plastic or rubber), sand, and gravel are able to prevent exchange between the sediments and the water column. Once anchored or deposited on the sediments, these materials can remain effective for years. The rate of sediment accumulation on top of these materials generally determines how long they will remain effective. Sheeting can be periodically removed, cleaned, and reinstalled to prolong its effectiveness.

The cost of purchasing and installing a sediment cover varies with the material selected. Use of the synthetic sheeting or netting is more expensive than sand or gravel. Costs range from $200 to $20,000 per acre (Mass. DEQE, 1982b).

8.0

SUMMARY OF WATER QUALITY PROBLEMS & EVALUATION OF CONTROL OPTIONS

The waters of the Upper Mystic Lake Watershed, particularly the Lake itself, are a significant natural and recreational resource. Upper Mystic Lake is one of the largest lakes in the Boston metropolitan area and, with close to half its shoreline publicly owned, is also one of the most accessible. As such it is popular for swimming, boating and fishing. Use of the Aberjona River is more limited because poor water quality is more evident and in general facilities and attractive access points are limited. The linear park along the Aberjona between Winchester center and the Lake is a good example of how the natural features of the river can be developed but its attractiveness is limited by water quality particularly during low flow conditions.

Chapter 6.0 described existing water quality conditions within the Upper Mystic Lake Watershed and the impact of these conditions on use. This chapter focuses on the water quality problems of Upper Mystic Lake specifically related to:

(1) public health concerns for contact recreation,

(2) nuisance aquatic vegetation,

(3) maintenance and improvement of game fisheries, and

(4) suitability of fish for human consumption.

The problems relating to each of these concerns are summarized and the contributing sources of pollution identified. The applicability of the various control options is then evaluated and suggestions regarding what should be done next presented.

8.1 MAJOR WATER QUALITY PROBLEMS

Public Health Concerns for Contact Recreation

The Upper Mystic Lake is a popular swimming and boating area. An MDC beach facility, Sandy Beach, is located in the northeast corner of the main basin. Local residents and members of the boat clubs on the Lake also swim in other areas along the shoreline. Sailing and wind surfing are also popular activities.

In waters used for contact recreation, contamination from disease-causing organisms is a major concern. The most common source of these pathogens is sewage. Coliform bacteria are used as indicator organisms to detect contamination, as they usually outnumber and live longer than pathogens. Thus, the standards established for Class B waters and for bathing areas are designed to protect individuals by limiting the allowable coliform level in bathing areas. While total coliform standards exist fecal coliform is considered a much better indicator of pathogen presence. In Upper Mystic Lake, the MDC analyzes samples collected off Sandy Beach for coliform levels on a weekly basis during the swimming season. The three boat clubs on the Lake do not test for coliform; it is unknown whether any lakefront residents have testing done. Probably Sandy Beach is the only area regularly monitored.

Sampling for the Mystic Urban Runoff Project has shown that coliform counts were often high in both forebays and occasionally near the outlet. These conditions were found during both dry and wet weather, although counts after storms were highest. This poses a threat to the health of individuals exposed to waters while contamination is present. In addition, Sandy Beach exceeded the MDC coliform standard in July 1982 and warnings that swimming may be hazardous to public health were posted for several days.

Studies have pointed to several areas where sewage is entering surface waters. Most comes from periodic combined manhole overflows to Sweetwater Brook, but six areas in Winchester's sewer line also occasionally surcharge. Two of these sites discharge directly to the Lake. Inadequate capacity in the sewer line located along Route 3 causes overflows to the stormwater line which drains to the lower forebay. Samples collected from the Route 3 stormwater outfall during wet and dry weather reflected this problem. Additionally a stormwater outfall between the two forebays is used as a relief line for the inverted siphon in the sewer line which runs under the Lake.

Two other areas of concern were indicated from test results. Elevated bacteria levels were found in the Boat Club Inlet and at the Lake outlet, but the sources of contamination were not identified. An investigation of the Boat Club Inlet led to sampling of the stormwater line which drains to the inlet upstream of Everett Avenue. High coliform counts were detected in several areas, but they were still below levels detected at Everett Avenue indicating that an additional problem exists at some point along the inlet. High bacteria counts were also recorded at the outlet of the Lake. Complaints made by a member of the Medford Boat Club pointed to sewage contamination from an unidentified pipe along the shoreline. Possibly this was due to sewer line overflows to the stormwater line in Arlington. Further investigation of these two problems is needed to identify their sources.

There may be additional sources of coliform contamination which are undetected at this time. Urban runoff contributed to the bacteria load during wet weather but, comparatively, was much less significant than the sanitary sources. The Sweetwater Brook sanitary contribution was by far the greatest source. Separation of the sewer and stormwater lines in Stoneham was estimated to reduce mean total coliform concentrations at the USGS gauge by 66% (CDM, 1982). However, the other sources should not be ignored. Their proximity to the Lake makes them a significant threat to public health.

Nuisance Aquatic Vegetation

Upper Mystic Lake suffers from excessive aquatic vegetation. Rooted plants are abundant throughout the forebays, in the channels between the forebays and along the shoreline of the main basin, particularly in front of the outlet dam and West Shore Inlet. Excessive algae growth often clouds the surface waters of the Lake, particularly in the forebays. This nuisance vegetation impacts both the recreational potential and aesthetic value of the Lake.

This study determined that phosphorus is the major factor controlling vegetation growth in the Lake. The average concentrations in the Lake exceeded the recommended U.S. EPA phosphorus guidelines to prevent nuisance aquatic plant growth by a factor of 3. The highest in-lake values were 20 times in excess of that guideline. In-lake phosphorus concentrations were significantly higher following storms as a direct result of increased wet weather loads from the Aberjona River and Boat Club Inlet. Present phosphorus levels in the Lake are similar to levels observed in 1974. However, present hypolimnetic concentrations are higher than in 1974 as a result of increased phosphorus release from the sediments. A Vollenweider plot based on present phosphorus loadings to the Lake clearly classified the Lake as eutrophic.

The annual phosphorus load to the Lake was estimated as 6450 lb/year with the Aberjona River, Boat Club Inlet and internal sediment release comprising 97% of this load as follows:

Aberjona River	
baseflow	27.8%
urban runoff	24.2%
Sweetwater Brook sanitary	20.0%
Boat Club Inlet	
baseflow	8.1%
urban runoff	5.3%
Internal sediment release	11.6%

Approximately 60 percent of the phosphorus load from the Aberjona was in particulate form much of which settles out in the upper forebay.

The Vollenweider plot was used to estimate how much the phosphorus load would need to be reduced to approach mesotrophic and oligotrophic levels. To achieve mesotrophic conditions, the annual load would have to be reduced by 77 percent, and for oligotrophic 90 percent. These reduction estimates are based solely on this model which, while it is a useful indicator, should not be misconstrued as an exact representation of the Lake. Using 77 percent as a goal for reduction the relative contributions of the various sources listed above can be combined to consider various generalized control strategies. For example, controlling all inputs from the Aberjona would result in a 72 percent reduction; or controlling the Sweetwater sanitary connection, internal sediment release, and urban runoff a 61 percent reduction. From these two examples it is obvious that a 77 percent reduction or even a 60 percent reduction will be difficult to achieve. It is crucial, therefore, that as much phosphorus be controlled as possible. It is also apparent that even with watershed controls, in-lake treatment may be required.

urban
runoff
contribution

Maintenance and Improvement of Game Fisheries

The Upper Mystic Lake is a popular fishing area for local residents. Under existing water quality conditions only warm water species (e.g. bass, pickerell, bluegills) can survive, but residents have expressed a desire to establish a stocking program for cold water species (e.g. trout).

The maintenance of a game fishery is dependent on the health and well-being of the entire aquatic community. The total absence of sediment dwelling macroinvertebrates in the Lake is indicative of a very disturbed community. Fish kills and increased occurrence of flesh lesions and disease have been reported by local residents in 1982 although cause has not been determined. The 1981 Division of Fisheries and Wildlife survey showed an abundance of pan and forage fish which are generally more tolerant of polluted waters than game fish. However, the growth rate data collected indicated that the existing fish populations are relatively healthy. In terms of the water quality conditions required to support a game fishery, several major problems were identified including dissolved oxygen distribution, high ammonia and metals concentrations and bacterial and viral contamination from sanitary discharges. While each of these conditions is important by itself, it should also be remembered that in combination they can create a stressed environment and make the organism more sensitive to a particular pollutant.

The lack of dissolved oxygen below 30 feet in the main basin during stratification is a concern in two regards:

(1) the temperatures required to support cold water fish are found in deeper waters where dissolved oxygen requirements are not met, and

(2) under anoxic conditions, potentially toxic metals can be released from the sediment.

During this study the amount of oxygen demanding material entering the system from external sources (e.g. urban runoff) was quantified, but an internal oxygen demand (e.g. that required to decompose algae and aquatic weeds) could not be determined from the information collected. Of the external demands, the oxygen required to oxidize organic and ammonia nitrogen could be as much as three times that required for the decomposition of organics (BOD). Based on the analysis, however, the internal demand appears to be a significant factor; therefore, it must be reduced significantly to maintain adequate oxygen levels in the Lake. This goes back to the problems discussed above regarding excessive vegetation.

In addition to the oxygen demand exerted by the high ammonia levels both ammonia-nitrogen and nitrite-nitrogen levels were observed in the Lake at levels potentially toxic to aquatic life. The major source of this nitrogen is industrial waste disposal at the Olin Chemical site in Wilmington. This is reflected by the baseflow contribution of 63% of the total ammonia load. Nitrogen levels along the Aberjona River and in the Lake have steadily decreased over the past 15 years, and correspondingly the occurrence of potentially toxic levels in the Lake has decreased.

Concern is also warranted regarding the concentrations of certain metals found in the Lake. Levels of aluminum, copper, iron, manganese, cadmium, lead and zinc were found at potentially toxic levels based on U.S. EPA criteria for a "healthy aquatic environment". Baseflow was a major source of iron and zinc and to a lesser extent aluminum; urban runoff was a major source of manganese, lead, iron and copper; and the Sweetwater Brook sanitary connection a major source of aluminum, copper, lead and zinc. Unfortunately, the sediment contribution could not be calculated with the limited data collected but, based on accumulation seen over the stratification period, it may be a significant source of manganese, iron, and zinc. Possible sources of baseflow metals need further investigation as does the source of iron coming from the Niles Lane stormwater outfall and the contribution from sediment release.

Suitability of Fish for Human Consumption

Given the high levels of metals found in the Lake, there is a concern regarding the suitability of Lake fish for human consumption. Unfortunately, the only existing Food and Drug Administration standard is for mercury. Fish flesh samples analyzed did not exceed that standard. Other criteria with which to compare the fish flesh metals concentrations could not be found.

General conclusions can be drawn using U.S. EPA guidelines which take into account metals concentrations in the water. Based on these guidelines, levels of lead and arsenic observed in the Lake water were a potential threat. The Massachusetts Division of Fisheries and Wildlife recommends eating bullheads in moderation due to lead levels found and concluded that otherwise, based on metals levels, there is no immediate threat to public health. As mentioned above the major sources of lead are the Sweetwater Brook sanitary connection and urban runoff. Additionally, urban runoff contributed 70% of the arsenic load to the Lake. They recommended further study of metal content by age/size classes. Reported fish kills and flesh lesions and disease also need investigation.

It should also be noted that metals are not the only pollutants of concern regarding the suitability of fish for human consumption. PCBs and other organics of concern were not tested for in this study but may be an additional threat. Additional sampling for these constituents is needed.

8.2 EVALUATION OF CONTROL OPTIONS

Four major sources of pollution to the Upper Mystic Lake were identified as part of the Mystic Urban Runoff Project. For the pollutants of concern (nitrogen, phosphorus, coliform, and metals), their sources are as follows:

Source	Pollutant
Urban Runoff	Phosphorus, Metals
Combined Sewer Overflows or Other Sewer Line Faults	Phosphorus, Coliform, Metals
Baseflow	Nitrogen, Phosphorus, Metals
Internal Sediment Loads	Phosphorus, Metals.

Controlling these sources and the impacts they have on Upper Mystic Lake can be accomplished in two ways: (1) the source of the pollution can be controlled through watershed controls, or (2) the symptoms of the problem can be temporarily treated using in-lake controls. Source control is preferred as it has a more permanent impact, but for non-point sources it is often difficult. The control evaluation of this project consider both of these types of control, as discussed below.

Watershed Control Evaluation

Urban Runoff. Controlling urban runoff pollutants in the Watershed will be extremely difficult due to their widespread distribution. The stormwater modeling done under this project did not identify any critical areas where the areal contribution (lbs/acre) of urban runoff pollution is pronounced; therefore, pinpointing certain sites where particular runoff controls would be most effective was not possible.

A major difficulty in terms of controlling urban runoff in this Watershed is the design of the stormwater collection systems. Stormwater is generally discharged at a large number of locations, over 150 in all, within each community instead of only a few points. The expense of installing and maintaining a treatment device at each outfall, such as swirl concentrators or helical bend regulators, or constructing interceptors to transport the runoff to one location for treatment, would be prohibitive. Similarly, the construction of new detention basins, grassed waterways, and filter strips may be difficult or costly to site within the highly developed Watershed.

In areas where development is still occurring or where existing drainages are being altered or repaired, erosion and sedimentation and volume reduction controls, as described in Chapter 7.0, should be required to prevent further water quality degradation. Conservation commissions and planning boards can

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require developers to minimize the size of the disturbed area and to use controls such as diversions, slope stabilization practices, and sediment basins and traps. The selection of controls will vary for each construction site. Development drainage plans should minimize the net change in the quantity and rate of runoff from a site prior to the proposed development. Proper maintenance of catch basins through regular removal of collected residual can reduce loads of suspended materials including lead, organic matter, and phosphorus. The optimum cleaning frequency is site specific, but each community can identify areas where sediment deposition is greater and more frequent cleaning called for.

Source controls which reduce the amount of pollutants available to be collected by runoff, are probably the most practical control method in this Watershed. Operation and maintenance practices such as street sweeping and road maintenance can reduce the amount of particulate matter available to be washed off. As with catch basin cleaning, the optimum frequency for street sweeping varies with the costs incurred weighing against water quality improvement. Street sweeping is not a particularly effective means of phosphorus control, but can remove up to 35% of the lead present on roadways. Again, towns can identify areas of particular concern, which for lead are generally the more heavily trafficed areas, and increase sweeping to the extent possible. Although street sweeping may not be the most efficient, it is probably more cost-efficient than most of the options available.

Educating the public on methods of pollution reduction can also be an effective means of source control. Brochures outlining guidelines for proper automobile maintenance, fertilization and pesticide use, and solid waste disposal, as well as the water quality benefits attained from reducing the pollutants coming from these sources, can be distributed to the public. Often people are unaware that some of their activities pollute the environment and that their activities can affect their downstream neighbors. Enforcing existing fines for littering or instituting new fines would also reduce pollution to some extent. Not only will this generate revenue, but it will also improve the appearance of the community. Often this added incentive is needed to bring about a noticeable response. While implementing source controls on an individual basis may seem to have an insignificant effect, the cumulative effect of widespread control can result in significant improvements in water quality.

Sanitary/Stormwater Connections. Contamination of stormwater runoff and subsequently surface waters by sanitary discharges is a major problem in the Watershed contributing large quantities of phosphorus, certain metals, and bacteria to Upper Mystic Lake. Funding for the separation of 19 combined manholes in Stoneham, the major contributor, will not be available until a study of the town's pumping station is completed.

Winchester has completed a facilities plan for the correction of several problems resulting in sewer surcharging, two of which discharge directly to the Lake through stormwater outfalls. They have also developed a ten year strategy for completion of the corrective measures using town funds. If state funds are made available this work could be done much sooner.

Arlington is currently conducting an infiltration/inflow study which should identify problems in that system. The Arlington drainage to the Lake should be included in that effort in an effort to find the source of high coliform levels recorded at the Lake outlet. A plan for eliminating sewer surcharging to Horn Pond in Woburn needs to be developed. It has been suggested that excessive infiltration/inflow to the sewer system in Woburn is a contributing factor. This should be investigated.

Baseflow. Baseflow, the water which supplies flow during dry weather (usually groundwater), was found to contribute unusually high amounts of nitrogen, phosphorus, and some metals. Normal background levels account for some of the baseflow load, but groundwater contamination is evident. As discussed, the baseflow loads calculated reflect to some extent dry weather sewer overflows to Sweetwater Brook. High levels of zinc and phosphorus were occasionally recorded in Sweetwater Brook during dry weather, however, baseflow contributions above the confluence of the Aberjona and Sweetwater Brook were also high indicating that baseflow alone is a significant source.

High ammonia levels in the Aberjona River and Upper Mystic Lake are primarily due to groundwater contamination in Wilmington at the Olin Chemical site which discharges to drainage ditches on site and then flows down to Halls Brook and the Aberjona River. High iron concentrations have been attributed to leachate from the Woburn Landfill, but elevated concentrations have also been seen in the railroad drainage ditches above that site. Manganese levels were also high in these ditches. Further investigation is needed to try to locate the sources of the iron, manganese and phosphorus contamination found in the baseflow. Baseflow contributions are extremely difficult to control. The instream detention area discussed below could, however, reduce those contributions through settling and plant uptake.

In-Lake Control Evaluation

All of the in-lake controls presented in Chapter 7.0 could be implemented in the Upper Mystic Lake, but many would be expensive, yield minimal results, and/or be harmful to aquatic organisms. It is also important to emphasize that many of these controls will have only limited effectiveness unless Watershed controls are in effect. The advantages and disadvantages of each will be discussed below, ending with the controls believed to be best suited for Upper Mystic Lake.

Biological treatment, involving introduction of predator organisms, is a new practice for controlling aquatic vegetation which has many potential drawbacks (see Chapter 7.0). Although this is a promising technique and may be better understood after future studies, currently this practice is not recommended and is often illegal. Chemical treatment for vegetation growth control is costly and may require repeated applications due to the eutrophic status of the Lake. Also, the buildup of chemical residues may be harmful to aquatic organisms and consequently it is generally not recommended.

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Flushing or draining the Lake to remove the polluted water is also an impractical control option for several reasons. The release of all the water from the Lake may be difficult, if not impossible, due to the depth of the main basin; downstream hydrology may be adversely affected if the release is not controlled carefully; refilling the Lake with high quality water may be a slow process; and aesthetically, the appearance of a drained Lake may be unpleasant to local residents. Over winter drawdown, designed to control rooted aquatic plant growth, has problems similar to flushing, but additionally, the most abundant aquatic weed within the Lake, *Potamogeton*, has been found to increase its growth after drawdown.

Chemical precipitation and inactivation of the phosphorus in the water column and sediments, respectively, is an expensive control which may only be effective for short lengths of time. To maximize the effectiveness of this treatment, phosphorus inputs to the Lake would need to be reduced significantly. However, the phosphorus loads from baseflow are high enough to support some aquatic vegetation growth, making phosphorus precipitation/inactivation an unfavorable control.

Dredging may effectively remove the pollutants held in the sediments and some rooted aquatic plants, but the potential disadvantages outweigh the benefits. The sediments in Upper Mystic Lake contain high concentrations of metals and may be difficult to dispose of properly. Also, dredging may resuspend sediments and result in the release of pollutants affecting both the Lake and downstream waters. Sediment covering to prevent release of phosphorus and metals using clay or fly ash is not recommended due to the difficulty in settling the clay and because of the potential release of heavy metals.

Aeration of the Lake water is one of the more favorable control options available. Both artificial destratification and hypolimnetic aeration will put oxygen in the water column, inhibit phosphorus and metal release from the sediments, and remove gases from the water column; but artificial destratification will eliminate the possibility of reestablishing a cold water fishery. Mixing the entire water column, as is done during artificial destratification, makes the water temperature uniform. This leaves no cold bottom waters which are needed to support cold water game fish such as trout. Both methods are expensive to establish, however MDC has the equipment needed for artificial destratification. The equipment is currently being used for a project being conducted on the Lower Mystic Lake, but could possibly be transferred at a later date to the Upper Lake. This would lower the initial capital investment costs. Operation and maintenance costs would reflect the frequency at which the aerators are used, since repeated aeration is required to keep oxygen in the bottom waters.

Controlling rooted aquatic plant growth can be effectively done by harvesting. This practice will need to be repeated at least once each year, but after numerous cuttings weed growth tends to be reduced. One disadvantage is that the phosphorus normally taken up by the weeds may encourage algal blooms, but controlling phosphorus loadings through Watershed controls could decrease the chances of this problem occurring. The use of fiberglass netting to inhibit rooted aquatic plant growth, although expensive, may be efficient when used in small areas. Lakefront residents could use netting to eliminate the weed problems adjacent to their property.

Another option, discussed as a Watershed control in Chapter 7.0 is the use of retention/sedimentation basins to remove pollutants. In effect, the upper forebay of the Lake is presently acting as a sedimentation basin and could be more effectively used if a baffle system was installed to further increase retention time and vegetation was harvested to prevent nutrients and oxygen consuming materials from entering the rest of the Lake. Occasional sediment removal would also be needed. This option does, however, have a major drawback. By utilizing the upper forebay for treatment purposes other uses would be restricted and aquatic vegetation would become more dense. Since this may not be desirable another possibility is to investigate the use of the Aberjona just upstream from the Lake for a similar purpose. This option needs to be further investigated.

8.3 SUMMARY

This project has identified a number of major water quality problems in the Upper Mystic Lake Watershed. While the focus of this final chapter has been on the Upper Mystic Lake, the problems discussed also reflect those found along the Aberjona River and West Shore and Boat Club Inlets. The Watershed is recognized as an important water resource and it is obvious from this study that a concerted effort is needed to improve water quality conditions in order to attain water quality goals. This effort must recognize that water knows no town lines and that upstream activities are affecting downstream neighbors. As in many urban watersheds, this will not be an easy task, but certainly is not an insurmountable one.

This project has identified various sources of pollution which need to be controlled, some of which still need to be further investigated. The control of sanitary sewer overflows will result in a significant improvement in water quality. Funding for such projects is limited, however, and local support is crucial. Urban runoff is a major source of a number of pollutants of concern. Unfortunately, no easy solution for controlling urban runoff exists. Controlling the sources of contaminants before they are picked up by runoff is the most feasible approach, but will require a great deal of diligence on the part of local officials and residents. The in-lake control options discussed above deserve serious consideration, but it is important to remember that they often only treat the symptoms and will have to be used repeatedly unless the sources of pollution are also controlled.

The results of this study can be used as a guide for action by local and state officials and Watershed residents. The following is a summary of next steps which should be taken with the ultimate goal of improving water quality in the Upper Mystic Lake Watershed.

Controlling Sources of Pollution

- Secure funding for combined manhole separation in Stoneham and Winchester's facilities plan for relieving surcharging sewer problems.

- Investigate the additional sources of bacterial contamination identified in Woburn, Arlington and Winchester as outlined in this chapter.

- Options for preventing ammonia laden water from flowing into Halls Brook from the Olin Chemical property in Wilmington should be given serious consideration.

- Organize community support to reduce urban runoff pollution to the extent possible through source controls.

- Investigate possible sources of the high levels of certain pollutants found in Aberjona River baseflow and the iron discharge from the Niles Lane stormwater outfall.

- Determine the importance of sediment release as a source of phosphorus and metals.

Defining Water Quality Goals

- Additional consideration should be given to the desire and feasibility of establishing a cold water fishery in Upper Mystic Lake, as this will, to some extent, define control needs.

Further Investigation of Water Quality Impacts

- The toxicity of metals and ammonia levels found in Upper Mystic Lake should be further investigated and the cause of fish kills and disease reported in the future determined.

- Fish should be analyzed for potentially toxic organics to better determine suitability for human consumption and guidelines for metal levels in fish flesh should be developed.

Evaluation of In-Lake Controls

- Based on results of additional investigation of the importance of sediment release and on decisions regarding the desire and feasibility of establishing a cold water fishery, the two aeration options should be evaluated.

- The feasibility of developing an instream retention area in the Aberjona should be evaluated.

- As a remedial action weed harvesting of the forebays and main basin shoreline should be considered.

Additionally, one crucial issue remaining is possible sources of funding for the various needs identified. As discussed in Chapter 1.0, the purpose of the Nationwide Urban Runoff Program was to make recommendations to Congress concerning federal funding for stormwater projects. The national analysis should be completed soon and recommendations are forthcoming. However, even if the prognosis is favorable, funding will most likely not be made available in the near future due to budget limitations. Consequently, the recommendations of this report were developed assuming that large capital expenditures, such as would be required to construct interceptor stormwater lines, were not feasible. Combined sewer projects are currently eligible for funding under the State's construction grants program but monies are limited and the issue is one of establishing priorities. Communities can of course fund projects without federal or state aid but are also faced with budget problems.

Funds available under the Federal Clean Lakes Program are presently extremely limited and only allocated to ongoing projects. More funds may be made available in the future, but that cannot be counted on. In Massachusetts, legislation was enacted in December of 1981 establishing a Massachusetts Clean Lakes Program and providing as much as $3 million a year from an existing state bond. Regulations for that program are currently undergoing public review and DEQE will begin accepting applications sometime early next year.

ABBREVIATIONS

CDM	Camp Dresser & McKee, Inc.
EDP	Environmental Design and Planning, Inc.
MAPC	Metropolitan Area Planning Council
Mass. DEQE	Massachusetts Department of Environmental Quality Engineering
DWPC	DEQE Division of Water Pollution Control
Mass. MDC	Massachusetts Metropolitan District Commission
Mass. WRC	Massachusetts Water Resources Commission
MRWA	Mystic River Watershed Association, Inc.
U.S. EPA	United States Environmental Protection Agency
U.S. FDA	United States Food and Drug Administration
U.S.G.S.	United States Geological Survey

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GLOSSARY

ABBREVIATIONS

cfs - cubic feet per second
mgd - million gallons per day

mg/l - milligrams per liter
ug/l - micrograms per liter
mg/m^3 - milligrams per cubic meter
mg/kg - milligrams per kilogram

EOP - end-of-pipe
IS - instream
STORM - Storage Treatment Overflow Runoff Model
RWQM - Receiving Water Quality Model

°C - degrees Centigrade
°F - degrees Fahrenheit

ppm - parts per million

Abbreviations for water quality parameters are listed in Table 3-4.

Acute Toxicity - any poisonous effect produced by a single short-term exposure that results in severe biological harm or death.

Advection - movement in a longitudinal (downstream)direction.

Aeration - the entry of oxygen into water.

Aerobic - the presence of oxygen.

Algae - simple rootless plants that grow in water bodies.

Algorithm - an equation used in repetitive calculations as in a mathematical model.

Alluvial - pertaining to flowing waters.

Anaerobic - the absence of oxygen (also anoxic).

Anion - a negatively charge particle.

Anoxic zone - an area where no oxygen is present (also anaerobic).

Aquifer - an underground bed or layer of earth, gravel or porous stone that contains water.

Atomic Absorption - an analytical test which measures the absorption of certain wavelengths by the sample.

Bacteria - single cell microorganisms that lack chlorophyll. Some cause diseases, others aid in pollution control by breaking down organic matter in water.

Baseflow - the water which supplies flow during dry weather (usually groundwater).

Basin shelf - a gently sloping area which drops off quickly at its edge to a deeper area.

Bathymetric map - a map showing the depth from the water surface to the lake bottom.

Benthic macroinvertebrates - bottom-dwelling invertebrates that are large enough to be retained by a no. 30 U.S. Series sieve.

Bioaccumulation - the buildup of a contaminant in organisms as you move up the food chain.

Bioassay - a test to determine whether certain water quality conditions are toxic to a certain organism.

Biochemical oxygen demand (BOD) - the dissolved oxygen required to decompose organic matter in water.

Biodegredation - the decomposition of organic matter.

Biomass - the quantity (weight) of living organisms in a particular area of volume.

Biota - the plant and animal life of a region.

Cation - a positively charged particle.

Chemical oxygen demand (COD) - a measure of the oxygen needed to break down all organic and inorganic compounds.

Chronic toxicity - any poisonous effect produced after long-term exposure to a contaminant that results in severe biological harm or death.

Composite sample - the combination of a number of samples into one sample for analysis.

Deposition - the settling of solids to the bottom of a lake or stream.

Die-off-rate - mortality of a group of organisms which, assuming exponential decay, is the slope of a semilogarithmic plot of number over time.

Diffusion - the mixing of two or more substances by molecular motion.

Dimictic - the classification of a lake that undergoes a spring and fall turnover, typical to temperate lakes.

Dispersion - the mixing of two or more substances by outside influences such as turbulent flow.

Diurnal - occurring in a daily cycle.

Drawdown - lowering the water level of a lake.

Educator - a method of catch basin cleaning similar to vacuum methods.

Endotoxin - toxic substances liberated by the disintegration of cells.

Eutrophic - the state of a lake in which nutrient enrichment causes a rapid increase in productivity, often resulting in nuisance algal blooms, low transparency, extensive aquatic plant growth and loss of dissolved oxygen.

Epilimnion - the upper layer of water in a stratified lake located above the metalimnion.

Evapotranspiration - the total of the water lost to the atmosphere through surface water evaporation and plant transpiration.

Fecal coliform - the portion of the total coliform bacteria group which is contributed through the wastes of warm blooded animals, and are often used as an indicator of sewage contamination in waters.

First flush - the initial increase in a contaminant's concentration in waterways, resulting from runoff's removal of the majority of pollutants accumulated on roads, etc., during the first part of a storm.

Flow regimes - categories of the high, medium, and low flows characteristic of a specific river or stream.

Fluorimetric measurement - the analysis of the ability of a substance to absorb radiant energy at one wavelength and emit it at a longer wavelength.

Flushing rate - the rate at which a given volume of water in a water body is replaced by an equal volume of water.

Food chain - a hierarchy of organisms with each level feeding on the level below it (e.g. algae-fish-man).

Frost heaving - the disruption of a paved surface due to the expansion of water when freezing to ice.

Gneiss - a color banded metamorphic rock.

Granite - a common, coarse grained, light colored hard igneous rock.

Groundwater - the subsurface water which is located in soil and rock formations that are fully saturated.

Hazardous waste - a waste that poses a substantial threat to human health or the environment when improperly managed.

Helical - spiral.

Heterocyst - a large cell found in some algae which allows them to use nitrogen from the atmosphere.

Heterotrophic - relying on other organisms as food sources.

Hydraulic - the physical science and technology of the static and dynamic behavior of fluids.

Hydraulic budget - a simple accounting system, identifying sources and losses of water from a system.

Hydraulic routing - tracing the path of water as it moves through a system.

Hydrology - the science dealing with the properties, distribution and circulation of water on the surface of the land, underground and in the atmosphere.

Hypolimnion - the bottom layer of water found in a stratified lake below the metalimnion.

Igneous rock - rock formed by volcanic action or great heat.

Impoundment - an area in which a liquid can be contained.

Infiltration - the action of water moving through small openings in the earth as it seeps into the ground.

Invertebrates - animals without backbones, such as insects and crustaceans.

Ion - an electrically charged atom or particle.

Lake metabolism - the sum total of chemical processes such as decomposition, occurring within a lake.

Lake morphology - the form and structure of a lake basin.

LC_{50} - median lethal concentration, a standard measure of toxicity. A measure of the concentration of a substance which will result in the death of half an experimental population.

Leaching - the process by which a substance is removed from a material by a liquid filtering through it. This sediment laden fluid is called leachate.

Legume - plants with the ability to store nitrogen (e.g. members of the pea family).

Limiting nutrient - the nutrient required for plant growth, either phosphorus, nitrogen, or carbon, which is present at the lowest concentrations relative to plant growth needs.

Limnology - the study of the physical, chemical, and biological aspects of fresh water.

Littoral zone - the zone along the shoreline of a water body in which rooted plants can grow.

Load - the quantity (i.e. mass) of material which enters a water body over a given interval.

Macrophytes - large aquatic plants such as water lilies, pond weed, etc.

Meander - to follow a winding path.

Metalimnion - the layer in a thermally stratified body of water, between the epilimnion and hypolimnion.

Metamorphic rock - rock which has been changed in form by heat or pressure.

Model - a mathematic representation of a physical system.

Morphometric - the measurements pertaining to the morphology of a lake basin such as volume, depth, surface area and shore length.

Nonpoint source - a source of pollution that cannot be traced to one particular spot. An example is urban runoff.

Nutrient - a substance or ingredient which nourishes aquatic life.

Nutrient budget - a simple accounting system identifying sources and losses of nutrients.

Oligotrophic lake - a deep clear lake with low nutrient supplies containing little organic matter and high dissolved oxygen levels.

Organics - chemical compounds containing carbon atoms.

Organic matter - materials derived from plants or animals.

Outfall - the pipe at the end of a stormwater collection system (or treatment plant) which discharges to a water body.

Overland flow - water which runs off the land surface into a receiving water without entering a collection system.

Oxidation - the combination of a substance with oxygen, or, the removal of electrons (negatively charged particles) from an atom.

Oxygen deficit - (1) the difference between the amount of oxygen found in the water and the maximum amount possible based on solubility; (2) the difference between the amount of oxygen (by weight) in a given volume of water at one time (e.g. spring) and the amount remaining at some later time (e.g. autumn).

Pathogens - organisms, usually bacteria or viruses, capable of causing disease.

pH - a measure of the acidity or alkalinity of a material, liquid or solid. pH is represented on a scale of 0 to 14 with 7 being a neutral state, 0 most acid and 14 most alkaline.

Photic zone - the area from the surface of a water body to the maximum depth to which light penetrates.

Photosynthesis - a chemical process occurring in plants whereby carbon dioxide and water are synthesized into carbohydrates.

Phytoplankton - microscopic plants found in lakes and rivers.

Plankton - microscopic plants or animals found in lakes and rivers.

Precipitate - fall out of solution.

Priority pollutants - a group of 129 toxic chemicals or classes of chemicals listed in the 1977 Clean Water Act.

Pollutant sinks - locations where pollutants are removed from the water, (e.g. sediments).

Point source - a point from which pollutants are discharged (e.g. a pipe).

Productivity - the total quantity of organic material produced by organisms within a given period.

Profile - a vertical cross-section, usually referring to a sequence of samples taken at pre-determined intervals from the lake surface to the sediments.

Reduction - the removal of oxygen from a substance, or, the addition of electrons (negatively charged particles) to an atom.

Retention time - the amount of time that water is retained or held in a lake before it is flushed out.

Salmonoids - a family of fish including salmon and trout.

Sediment - the solid material that settles to the bottom of a river or lake.

Seiche - movement back and forth of the water in a lake or other land-locked body of water, varying in duration, and resulting in fluctuation of the water level.

Sensitivity analysis - testing a model to determine how changes in one variable will affect the result.

Short circuiting - the direct movement of water without mixing or dispersing as when incoming water takes a direct path to a lake's outlet.

Sump (catch basin) - an area below the catch basin outlet designed to collect sediments.

Super-saturation - when water contains more dissolved oxygen than is soluble at that water temperature.

Swale - a hollow or depression.

Symbiosis - dissimilar organisms living together in a mutually advantageous relationship.

Time-of-travel - the time it takes a volume of water to travel from an upstream point to a designated downstream point.

Thermal gradient - the change in temperature with depth.

Thermal stratification - a condition which develops in a lake where temperature differences within the water column cause the water to have different densities at different depths; thus three separate zones are formed - the epilimnion, metalimnion and hypolimnion.

Thermocline - the point of maximum rate of temperature decrease with depth.

Topography - the physical features of a surface area including relative elevations and the position of natural and manmade features.

Total coliform - a group of bacteria primarily coming from animals and soils, commonly used as indicators of sewage contamination.

Trophic - pertaining to the degree of nutrient enrichment of surface waters (see eutrophic).

Trip blanks - bottles containing distilled water which are carried when sampling to detect any contaminants which may enter a sample from extraneous sources such as particles falling from the atmosphere.

Turbidity - a cloudy condition in water caused by particles which interfere with the passage of light.

Volatile organics - an organic substance which can evaporate (or volatilize) without applying heat or pressure.

Watershed - the area of land that drains into a river or lake.

Water column - the vertical profile of water in a lake from the surface to the sediments.

Water table - the level at which fluid pressure equals atmospheric pressure.

Weir - a dam across a water channel for diverting or for measuring the flow of water.

Zooplankton - microscopic plants or animals found in river systems.